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HIGHWAY RESEARCH RECORD

Number 335

Roadside Development and Maintenance

11 Reports

HIGHWAY RESEARCH BOARD

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11 Reports

Subject Areas

24 Roadside Development
40 Maintenance, General
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Foreword

Because it is difficult to separate certain aspects of studies dealing with roadside maintenance from those relating more directly to the ecological, aesthetic, and safety elements of roadside development research, it is considered appropriate to combine in one volume the papers pertaining to studies significant to the interests of 3 Committees.

Several papers deal with various facets of the effect of sodium and chloride salts on roadside vegetation. One researcher suggests that a "metabolic index," combining an index of the sodium and chloride ions in leaf cells and twig tissue, be used as a diagnostic tool in determining tree health. In a study conducted as part of the NCHRP program, it was determined that the damage suffered by roadside silver maples resulted from chloride toxicity rather than the osmotic effect of the sodium salts in the soil solution. Another study revealed that optimum quantities of nitrogen tended to minimize the harmful effects of salt on growth.

Questionnaires and interviews were used in a rest area usage study in an effort to determine rest area needs in terms of facilities and spacing.

Researchers in Virginia report that crown vetch can be effectively used to revitalize deteriorating vegetation on slopes by controlling nitrogen availability.

Five papers report activities regarding roadside maintenance and equipment. One of these papers details the results of studies to improve the performance of mowing machines, mulchers, and spray nozzles.

A rapidly spreading recognition of the importance and preservation of environmental quality is reflected in a paper that reports the effects of right-of-way mowing on wildlife. Controlled mowing in a midwest state favorably affected the population of birds and small animals and reduced mowing costs.

Weed control with various herbicides in Oklahoma and experiments in Georgia to evolve more effective seeding mixtures, and mulching and fertilizer practices are subjects of 2 papers that are pertinent to the maintenance-oriented agronomist and engineer.

A new concept in establishing vegetation in arid country is described in a paper concerning roadside planting in Montana. In order to tap the moisture reserves in the lower soil levels, seedlings were grown in "tubes," thus forcing root growth to extend in a downward rather than a lateral direction. Another means to supply moisture to newly installed plants utilized a plastic sheet that reduced evaporation and condensed soil moisture.

—Wesley L. Hottenstein

Contents

1968 National Rest Area Usage Study

LEON E. LITZ, NATHAN LIEDER, and HOWARD McCANN,
Office of Planning, Federal Highway Administration

Rest areas are required on the Interstate highways to provide safe stopping places. Yet the cost of constructing and maintaining rest areas with toilets, picnicking facilities, water for drinking, and other facilities is very high, and it is certainly not desirable to construct more facilities than needed. The 1968 National Rest Area Usage Study was undertaken to assist in determining rest area needs in terms of facilities and spacing by measuring the present demand for and characteristics of the use of existing rest areas. A detailed inventory as of January 1, 1968, revealed a total of 6,756 rest areas on the federal-aid and state primary highway systems, of which 784 were on the rural Interstate and 5,972 on the other systems. A total of 78,619 interviews were conducted during the summer of 1968. Of this total, 68,415 interviews were completed on the Interstate System and 10,204 on the other systems. Some of the significant findings are that approximately 4 times as many vehicles stop at rest areas with toilets than at rest areas without toilets; approximately two-thirds of all persons entering rest areas use the toilets, if available; and use of rest room, rest, and eat, in respective order of importance, are the principal purposes for stopping.

•DURING THE PAST DECADE, there has been an increasing emphasis on, and a recognition of, the need to provide adequate rest area facilities for the safety and convenience of highway travelers. This raises the question, When has adequate safety rest area service been provided? It is important to have enough rest areas to provide safe and appropriately spaced stopping places to break long trips. Yet the cost of constructing and maintaining rest areas with toilets, picnic areas, running water, and other facilities is very high, and it is certainly not desirable to construct more facilities than needed. As a basis for resolving this problem, measures are needed of the present demand for and characteristics of the use of existing rest areas.

Several states have made rest area studies during the past 10 years. Seldom have these been repeat studies in any area to measure trend. It appeared that such a piecemeal approach might not provide a state with sufficient information to make reliable forecasts of its rest area needs. It was, therefore, decided to collect data on rest area usage from a nationwide sample. This would reduce the amount of work required in any one state and yet provide a base of data that could be used by all states.

The first step in initiating a nationwide survey was taken during the fall of 1967 when an inventory was made of all rest areas that existed on federal-aid and state primary highway systems, excluding toll roads. This inventory included all rest areas that were planned to be in operation by the summer of 1968. One of the primary functions of the inventory was to provide the base from which rest areas could be selected to study rest area usage.

A rest area was defined for this study as follows: A roadside area that is separated from the main roadway, has provisions for stopping and resting for short periods, and has parking facilities for 3 or more vehicles.

Paper sponsored by Committee on Roadside Development and presented at the 49th Annual Meeting.

TABLE 1

PERCENTAGE OF VEHICLES STOPPING AT RURAL INTERSTATE (NON-TOLL) REST AREAS

Range	With Toilets		With Privies		Without Comfort Facilities	
	Summer Week	Peak Hours	Summer Week	Peak Hours	Summer Week	Peak Hours
Lowest	1.3	1.5	0.7	3.7	0.1	0.1
Median	7.8	9.0	8.7	8.2	2.0	2.6
Highest	15.0	19.5	12.2	12.7	7.8	6.7

The first inventory revealed a total of 6,756 rest areas, of which 784 were on the rural Interstate System as of the summer of 1968. Usage data were collected at 113 rest areas, sampled from this universe, 59 on the Interstate System and 54 on the remaining highway systems. These data were collected for a 7-day period for each of the 113 rest areas selected. Interviews were conducted for single 8-hour shifts, 10 a.m. to 6 p.m., Monday through Saturday, and for two 8-hour shifts, 6 a.m. to 10 p.m., on Sunday.

Drivers of 78,619 vehicles were interviewed during the summer of 1968. Of this total, 68,415 interviews were made on the Interstate System, and 10,204 on the remaining federal-aid and state highways. The percentage of vehicles stopping at rest areas on the rural Interstate System is given in Table 1. The median percentage stopping at rest areas having toilets or privies is approximately 4 times that for areas having no comfort facilities. The median of the percentage distribution of vehicle types entering rural Interstate rest areas with toilets is given in Table 2. The percentage of automobiles is slightly higher while the percentage of trucks and buses is lower during peak hours (12 noon to 4 p.m., Saturday and Sunday) than for a summer week (7 days, 8 hours from Monday to Saturday and 16 hours on Sunday).

Table 3 gives the median trip length, vehicle occupancy, and time spent in the rest areas. As expected, trip lengths are longer on the Interstate than on the non-Interstate highways. The median vehicle occupancy is slightly higher during peak hours than during the average summer week, but overall the median values are quite stable. The median time spent in Interstate rest areas varies from 18 to 20 minutes and is somewhat higher for non-Interstate areas. There is very little difference between summer week and peak-hour median values.

The median distance driven between stops as determined at rural Interstate rest areas with toilets is 107 miles from the start of a day's drive to the first stop and 74 miles between stops thereafter. Figure 1 shows the percentage of vehicles stopping in rest areas versus distance from the preceding rest area. If it is assumed that the present average percentage of vehicles stopping at rest areas on the Interstate with toilets (approximately 9 percent) will continue for the design period, then this curve indicates that a spacing of about 30 miles is desirable. Figure 2 shows the significance that distance to a succeeding rest area may have on the percentage of vehicles stopping in a rest area; no correlation at all could be made. Poor communication to the driver when he approaches a rest area as to how far it is to the next rest area may be a factor in this instance.

We also made similar plots of miles from preceding or to succeeding towns in an attempt to determine the significance that available comfort service facilities off the Interstate right-of-way may have on usage of rest areas. We were unable to determine any significant relationship.

TABLE 2

MEDIAN OF PERCENTAGE DISTRIBUTION OF VEHICLE TYPES ENTERING RURAL INTERSTATE REST AREAS WITH TOILETS

Vehicle Type	Summer Week	Peak Hours
Cars	76.6	80.8
Cars with campers or house trailers	5.3	5.7
Cars with other trailers	1.8	1.5
Trucks and buses	17.0	10.2

TABLE 3

MEDIAN TRIP LENGTH, VEHICLE OCCUPANCY, AND TIME SPENT IN REST AREAS

Item	Comfort Facility	Interstate		Non-Interstate	
		Summer Week	Peak Hours	Summer Week	Peak Hours
Trip length, miles	Toilets	915	878	446[a]	405[a]
	Privies	493	534	283	272
	None	890	634	272	192
Vehicle occupancy	Toilets	3.0	3.1	3.5[a]	3.2[a]
	Privies	2.8	3.1	3.0	3.3
	None	2.9	3.1	2.8	3.2
Time in rest area, min	Toilets	19	20	30[a]	33[a]
	Privies	18	20	21	30
	None	18	18	26	26

[a]Only one rest area is represented.

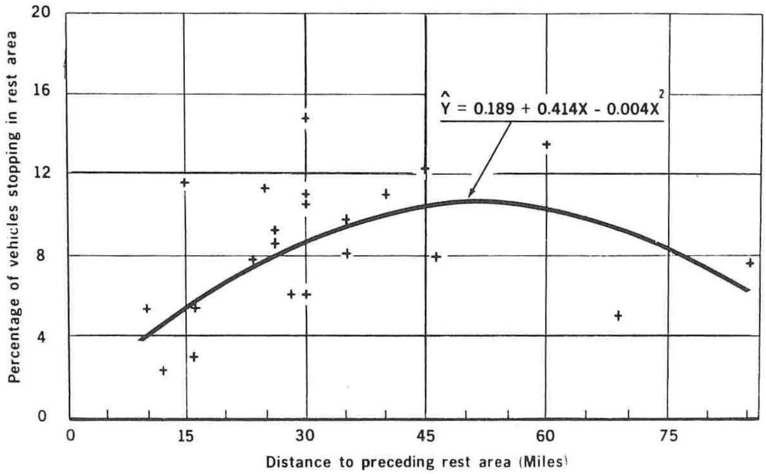

Figure 1. Percentage of vehicles stopping in rural Interstate rest areas with toilets versus distance from preceding rest area.

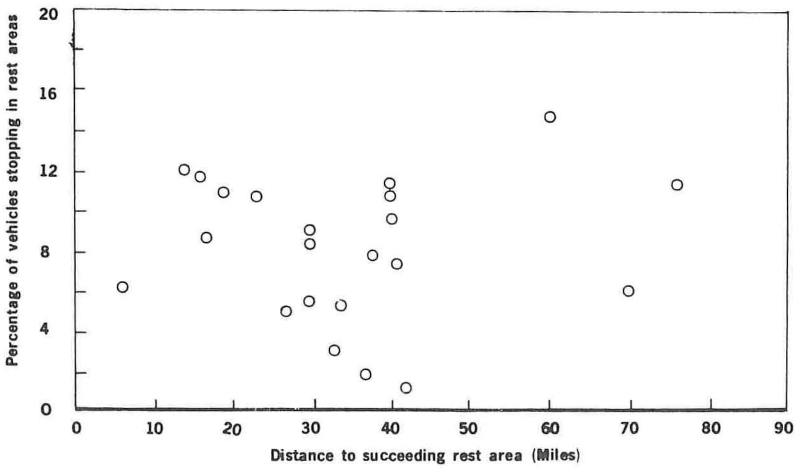

Figure 2. Percentage of vehicles stopping in rest areas versus distance to succeeding rest area.

One reason that no relationship could be determined may have been due to the great variation in accessibility of towns. For example, service facilities may have been adjacent to the right-of-way in some cities but several miles from the right-of-way in other cities.

The principal reasons given for stopping at rural Interstate rest areas with toilets were as follows:

Reason	Percentage of Vehicles
Use rest room	42.6
Rest	23.5
Eat	10.6

The actual usage of the facilities was as follows:

Facility	Percentage of Persons	Percentage of Vehicles
Rest rooms	74.0	—
Water	53.6	—
Waste disposal	—	14.9
Shaded table	—	11.6
Unshaded table	—	1.7

The average number of gallons of water consumed per vehicle during an 8-hour period was 7.6, based on 177,081 gal of water and 23,287 vehicles.

A representative distribution of duration of stay in rest areas was used to develop curves in an attempt to determine the maximum accumulation of vehicles in rest areas versus the hourly volume of vehicle arrivals (Fig. 3). This information can be used to develop curves from which the number of parking spaces can be determined (Fig. 4).

Guidelines on safety rest areas have been issued by the Federal Highway Administration and by the American Society of State Highway Officials. It is hoped that the results of this study in conjunction with these documents will provide better tools that the highway engineer can use in planning and designing rest areas.

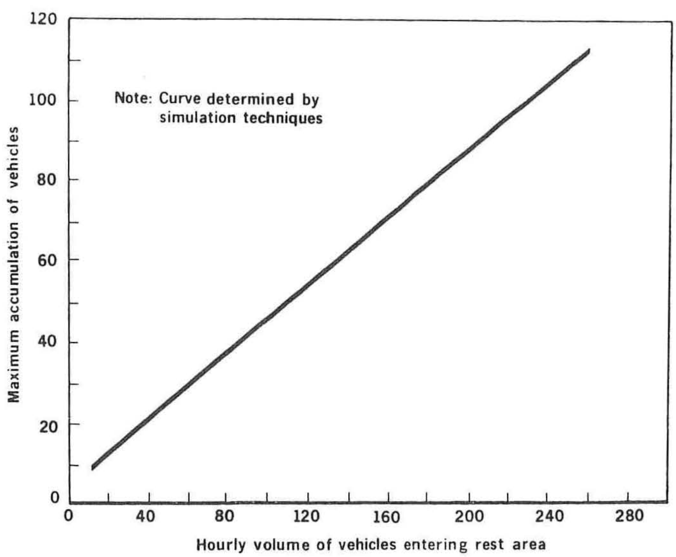

Figure 3. Maximum accumulation of vehicles in rest area versus hourly volume of vehicles entering rest area based on an average length of stay in rest area of 20 min.

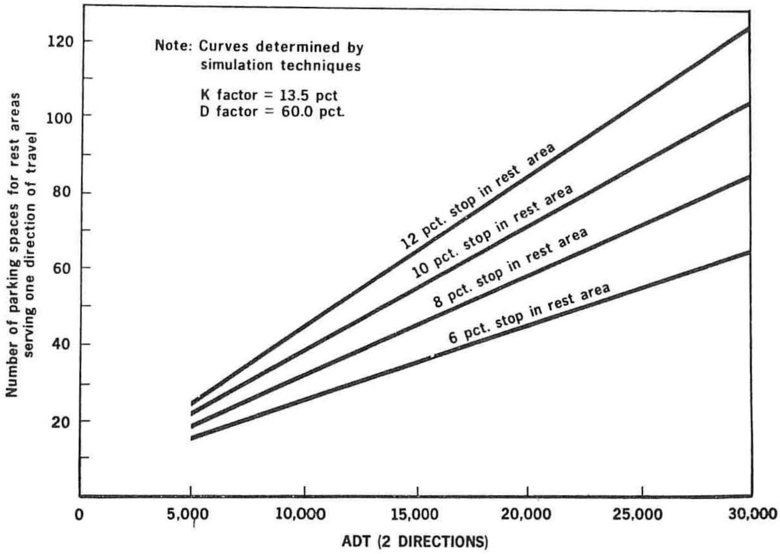

Figure 4. Parking spaces required for rural Interstate rest areas serving one direction of travel versus 2-direction ADT volumes for various levels of rest area usage and an average length of stay in rest area of 20 min.

A summary report has been prepared of the findings of surveys conducted at 113 rest areas during the summer of 1968 (1). The analyses indicated the need to concentrate all effort during the 1969 season on Interstate System rest areas with comfort facilities. Therefore, the 1969 surveys were conducted at 58 rest areas sampled from that stratum. The 1969 study was also designed to provide more information to evaluate better the effects that adequate commercial facilities located adjacent to or near the Interstate right-of-way will have on the spacing of rest areas on the Interstate System.

REFERENCE

1. 1968 National Rest Area Usage Study. Federal Highway Administration, Highway Planning Test. Tech. Rept. 16.

Metabolic Index as a Diagnostic Tool in Tree Health Determination

EDWARD F. BUTTON, Connecticut Department of Transportation

ABRIDGMENT

•PREVIOUS INVESTIGATIONS have established that levels of sodium and chloride in the leaves of sugar maples increase with the increasing exposure of the trees to road drainage (4, 6). Assessing the mechanism of toxicity of sodium or chloride to sugar maples is difficult because data on the normal and toxic concentrations of cations and anions in maple tissue are limited in the literature. In susceptible species, however, the toxic concentrations seem to be similar, and the mechanism of toxicity may be the same (1, 2). Chloride is reported to be lethal to peach trees at 1.0 percent of the dry weight of the leaf, with 0.5 percent producing serious leaf margin burn (3). Recent studies appear to establish similar toxic levels for sugar maples (4, 6). The 1966 Connecticut Study pointed out the possibility that trees obviously dying from the toxic effects of salt might fail to display alarming levels of Na or Cl in the leaf tissue because of the depressed metabolic rate and the reduced ability of the severely injured tree to take up moisture, nutrients, and salt from the soil (4). It was also stressed that a carry-over of accumulated chloride in woody tissue and the reduced rate of growth of older trees might be responsible for the more rapid accumulation of critical quantities of salt in the leaves of older trees, as mentioned by Bernstein (1, 2).

Although the manner in which the chloride ion is toxic to plants is not understood, certain hydrolytic functions by enzymes are suppressed and chlorophyll formation is depressed at high chloride concentrations. Visible symptoms on large trees may be delayed for several seasons after the appearance of high chloride levels in the leaves. The sodium ion is not readily or efficiently transported to the leaves until the latter stages of decline. In some cases in severely affected trees, nearly equal levels of sodium and potassium have been found, probably a lethal condition.

Data in the Connecticut Study indicated that sodium, through some mechanism, had suppressed the uptake of calcium, magnesium, and potassium. It is also possible that the significant presence of the negatively charged chloride ion in the cells depressed the natural production of negatively charged organic acids in the cell and thereby depressed the uptake, or negated the effect, of nutrient ions.

The Connecticut Study did suggest that high levels of Na and Cl had a depressing effect on the levels of Ca, Mg, P, and K found in the tissue. As a sequel to the previously published report (4), a method involving the relationship of the lethal Na and Cl ions to the essential Ca, Mg, P, and K ions found in the tissue has been devised (5).

To develop a tool to evaluate realistically the detrimental effect of exposure of a tree to chloride and sodium ions from de-icing materials, an intensive study of the levels of these ions as related to the levels of calcium, magnesium, phosphorus, and potassium ions also found in the plant tissue was initiated. The results of analyses of the tissue samples, obtained over a period of years from sugar maples at 3 locations, were assessed. The relationship of the ion levels to tree health is explored with 4 tree groups. The method of bringing the relationship of the harmful Cl and Na ions to the essential Ca, Mg, P, and K ions is brought into focus by employing the following ratio of all the ions found in the tissue.

$$\frac{\text{Ca} + \text{Mg} + \text{P} + \text{K}}{\text{Cl} + \text{Na}} = \text{index}$$

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The ions found are expressed as a percentage of dry weight of the tissue. Because leaf tissue responds more rapidly, and at a higher level than twig tissue from the same location on the same tree, the calculation is made for the leaf tissue and is called the leaf index. This index provides information on the effect, if any, of salt on the youngest cell tissue of the tree.

It has also been found that the harmful Cl and Na ions do gradually accumulate and persist in the woody tissue of trees that are continuously subjected to salt (4). The study of the levels of the harmful ions found in woody tissue over a long period of time does provide information on the gradual deterioration potentiality of the tree. It would appear that the same calculation should be employed by using the ions found in the twig tissue to derive a twig index.

It further appears that in some manner the two indexes, considered together, ought to present a simplified portrait of the metabolic condition of the tree. It is suggested that the following ratio of the 2 indexes can be used:

$$\frac{\text{leaf index} + \text{twig index}}{2} = \text{metabolic index}$$

The metabolic index appears to offer a realistic evaluation of the cumulative effect of exposure of roadside sugar maples to chloride and sodium ions polluting the root zone soil from seasonal applications of salts to the highway. It is proposed that other investigators explore this method of evaluation to assess the effect of salt on the general

TABLE 1

RELATIONSHIP OF METABOLIC INDEX TO OBSERVED TREE CONDITION

Metabolic Index		Tentative Health Category	Tree Condition
<5		a	Near death, recovery not possible
>5	<10	b	Severe defoliation, limb dieback, beyond recovery
>10	<25	c	Slight to serious leaf burn and limb dieback, depending on duration of exposure to detrimental factors
>25	<35	d	Very slight to no leaf burn, may show no signs of injury or decline if adverse conditions are eliminated
>35	<75	e	Good health
	>75	ee	Excellent health

TABLE 2

AVERAGE METABOLIC INDEX OF ALL TREE GROUPS

Group III Downslope[a]		Group II Upslope		Group IV Near Level	
Tree	Metabolic Index[b]	Tree	Metabolic Index[b]	Tree	Metabolic Index[b]
82-17-1	5 a	82-17-11	31 d	112-1	27 d
82-17-2	12 c	82-17-12	19 c	112-3	8 b
82-17-3	4 a	82-17-13	47 e	112-4	12 c
82-17-4	8 b	82-17-14	39 e	112-5	12 c
82-17-5	4 a	82-17-15	21 c	112-6	9 b
82-17-6	5 a	82-17-16	39 e	112-7	27 d
82-17-7	4 a	82-17-17	23 c		
82-17-8	7 b	82-17-18	28 d		
82-17-9	6 b	82-17-19	23 c		
82-17-10	3 a	82-17-20	23 c		

Note: Nonroadside control tree had an index of 81 ee.

[a]All downslope trees have been removed because they were either dead or hazardous.
[b]Refers to tentative health category in Table 1.

health of roadside sugar maples and other valuable tree species. It would appear that cellular biologists might also investigate the harmful reactions of Na and Cl ions that get into the plant cells and interfere with, or disrupt, vital life processes. The complete report (5) includes application of the metabolic index to sugar maples studied in Connecticut from 1964 through 1967.

Data given in Table 1 demonstrate the feasibility of employing the metabolic index in classifying the physiological condition of the tree as related to observed physical conditions. Table 2 gives the average metabolic indexes of the various groups of Connecticut sugar maples sampled and analyzed from 1964 through 1967. It must be pointed out that deriving the metabolic index from analyses obtained from one or two consecutive sampling dates proves of more value in assessing the effect, if any, of Na and Cl ions on the health of a tree at any given time during a growing season. The twig index might be also of value should a winter assessment be required.

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Effects of De-Icing Salts on Roadside Soils and Vegetation

L. W. ZELAZNY and R. E. BLASER,
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ABRIDGMENT

•A PUBLIC DEMAND to maintain open travel routes for fast speeds during the winter, an increased emphasis on traffic safety, and a change in economic factors have shifted winter maintenance operations in the north to application of salts directly to highways. This policy requires the use of liberal quantities of sodium chloride and calcium chloride. The effect of these de-icing salts on soils and vegetation in the highway environment is of importance.

De-icing salts applied to roads may be carried by surface runoff into streams and waterways or they may infiltrate into the soil bordering the highway. When infiltration occurs, ions of de-icing salts may be carried to groundwaters, remain in soil solution, or become adsorbed by soils. Therefore, salts are potential pollutants of water supplies and soils in the highway environment and may cause the loss of potable water or the ability of a soil to support desirable plant growth or both.

Salt injury to vegetation usually develops as a general growth reduction followed by leaf scorch and curling, leaf drop, stem dieback, and gradual decline in vigor resulting ultimately in death of the plants. Such damaged vegetation creates an unsightly condition that can decrease property value and run counter to the highway beautification programs. It also increases the cost of highway maintenance because of the replanting requirements for new highways and the removal of dead woody vegetation that is a hazard to motorists on old roadways. However, whether de-icing salt is directly responsible for the plant injury is still a controversial subject.

The purpose of this investigation was to determine the distribution and movement of de-icing salt ions in soil bordering the highway at a site in Vermont and to determine the possible role of these salts in causing an extensive silver maple decline in this highway environment.

The site examined is located 5 miles south of Shelburne, Vermont, on US-7. At one time, it contained about 250 trees that were primarily mature silver maples of a similar age and planted opposite each other about 15 ft from the edge of the highway. Because of the slope, highway runoff occurs primarily to the east side of the road. On this side of the highway, the trees are noticeably damaged and many are dead, while trees on the west side of the road are growing vigorously. The soil bordering the highway is primarily a Vergennes clay, a moderately well-drained soil developed from micaceous glacial lacustrine clays.

Leaf and twig samples of the silver maple trees were collected from both sides of the highway on 6 sampling dates over a 4-year period. Samples were dried and ground. Chloride was extracted with a 1:100 ratio of plant material and a mixture containing 0.1 N nitric acid and 10 percent glacial acetic acid. Sodium was extracted from a second portion of tissue that was dry-ashed and brought to a 100:1 ratio of solution to plant material with 0.3 N nitric acid. The chemical data were statistically analyzed by using the paired t-test. Trees growing on the west side of the highway were compared with

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trees growing opposite them on the east side of the road for each element at the same date.

Soil samples were also taken from both the east and west sides of the highway midway along the slope for 8 sampling dates during this same period. The samples were collected at 3-ft intervals from the road and at 3-in. increments in depth. The samples were dried, ground, and extracted for 1 hour with a 2:1 distilled water to soil ratio.

On the east side of the highway, where visual deterioration of silver maples was evident, the average sodium and chloride contents of the soil were much higher and the specific conductivity of the soil extracts were larger than those of the soil on the west side of the highway, at least in the area where tree roots were more prominent. The specific conductivity on the east side of the road averaged twice as high as that on the west side while the sodium and chloride contents were 6 and 10 times higher on the east than on the west side of the road, respectively. The average content of calcium extracted was not appreciably different on the two sides of the road. Average soil analysis for samples collected from the 9- through 21-ft intervals from the highway and 0- through 12-in. depth in the horizon on all 8 sampling dates is as follows:

Roadside	Specific Conductivity (μmho/cm)	Chloride (ppm)	Sodium (ppm)	Calcium (ppm)
East	1,045.9	268.4	243.4	59.4
West	482.1	26.8	40.2	73.4

The largest salt concentration in the soil occurred 3 ft from the pavement on the east side of the highway for the April 5, 1969, sampling date. Specific conductivity was 3,960 μmhos/cm (EC x 10^{-6}) and the contents of sodium and chloride were 1,080 and 2,577 ppm in the soil respectively. A specific conductance this large in a 2:1 water to soil extract would be classified as moderately saline and would restrict the growth of many plant species. The osmotic pressure caused by the salt in the soil system would be about 1.5 atmospheres. However, by the June 24, 1969, sampling date, the amount of salt in the soil diminished sharply, and the osmotic effect at this date was less than 0.5 atmospheres.

It is interesting to note that high concentrations of sodium and chloride occurred to a depth of 18 in. or more in the soil profile on the east side of the road even during the winter. It was evident that salts moved down into the profile during winter. This is contrary to the opinion that de-icing salts carried in drainage water would flow over frozen soil. Apparently, salts are capable of percolation into the soil horizon when the ground is frozen.

High concentrations of chloride and sodium were noted (Table 1) in the leaf and twig tissue of the damaged silver maples as compared to healthy trees. The concentration of chloride in the leaves and stems increased with higher tissue deterioration of silver

TABLE 1

AVERAGE CHEMICAL ANALYSIS IN PERCENTAGE DRY WEIGHT FOR TISSUES OF SILVER MAPLES

Sampling Date	Leaves				Stems			
	Chloride		Sodium		Chloride		Sodium	
	East	West	East	West	East	West	East	West
9-14-66	0.83[a]	0.30	0.04[a]	0.01	0.36[b]	0.18	0.05[b]	0.01
9-15-67	0.70[a]	0.26	0.03[a]	0.01	0.94[a]	0.22	0.05[b]	0.01
6-20-68	0.67[a]	0.15	0.03[a]	0.01	0.13[a]	0.07	0.04[b]	0.02
9-13-68	1.18[a]	0.32	0.05[b]	0.00	0.19[a]	0.09	0.02[b]	0.01
4-5-69	—	—	—	—	0.20[a]	0.14	0.16	0.14
6-24-69	0.83[a]	0.16	0.08[a]	0.01	0.27[a]	0.11	0.06[a]	0.01

Note: Statistical comparisons can only be made between trees on the west and east side of the highway for each element and plant part taken at the same sampling date.

[a]Significance at the 1 percent level.

[b]Significance at the 5 percent level.

maples. The increase was greater in the leaves than in the stems. After death, a decrease in the concentration of chloride occurred in stem tissues, which was at times even lower than that in healthy trees. Sodium also gave similar results, but the relationship was less pronounced. The greatest increase in tissue sodium as related to increased tissue deterioration occurred in the stem rather than in the leaf tissue. The percentage range was also greater for the sodium tissue content, although the actual range was an order of magnitude greater for the chloride tissue content.

Examination of this site reveals that de-icing salt sprays are of no consequence to the decline of these silver maples. No visual damage occurred on trees on the west side of the highway or on either side of the highway at the top or far bottom of the slope. Therefore, distance from the highway or prevailing winds could not be responsible for the observed phenomenon. Deterioration of the silver maples increased with higher exposure of the trees to roadside drainage. Dead trees were found at the bottom of the slope where drainage accumulation was maximum, while no visual decline occurred at the top or far bottom of the slope where drainage accumulation was minimum. However, some tree deterioration was noticed midway of the slope on the east side of the road where highway drainage occurred. Damage to the trees, therefore, appears to have resulted from the root uptake of sodium and chloride rather than from the salt spray.

The study indicated that highway salting practices have increased the concentrations of sodium and chloride and the specific conductance in the soil on the east side of the highway for the site examined. This was manifested in an extensive silver maple decline on the east side of the road, while healthy trees were growing on the west side of the road where, due to the slope, highway drainage was limited.

The maximum concentrations of sodium and chloride were generally found at the soil surface and nearest the highway pavement. The concentrations of salt in the soil increased during the winter and then decreased during summer and early fall. Sodium and chloride ions entered the soil profile during the winter and penetrated into deeper horizons as time progressed. Higher than normal concentrations of sodium and chloride were found to depths of 18 in. and distances of 75 ft from the pavement. As the years progressed, the quantity of sodium and chloride increased throughout the entire soil profile. It is suspected that the passage of large quantities of salt through soil profiles cause a deterioration of the physical properties of the soil, thereby causing a decrease in soil permeability.

The increase in sodium and chloride content of the soil solution was manifested. through increased uptake of these ions into the leaves and stems of the damaged trees. Deterioration of the silver maples resulted from chloride toxicity rather than from osmotic effect of the salts in soil solution. No damage was observed when the concentration of chloride was less than 0.18 percent. A chloride concentration of 0.20 percent produced leaf scorch and above 0.50 percent produced moderate leaf scorch, defoliation, and ultimately death of the tree. The concentration of sodium was much higher in the damaged than in the healthy trees and may possibly be one of the reasons for the overall deterioration of the silver maples. However, it does not appear to be totally responsible, because high concentrations of sodium were sometimes recovered in trees exhibiting no salt damage. It was noted that, with the onset of death, chloride and in some cases sodium were lost from the woody tissue. Therefore, tissue analysis of a dead or dying tree may fail to reveal large quantities of these ions. The effect of salt spray was apparently negligible.

During the winter season, the de-icing salts move both horizontally and vertically from the highway border. The amount of salt ions present at any given distance and depth depends on (a) highway de-icing practices, which include kind and amount of salt used, time of application, and snow-removal procedures; (b) climate, which includes amount of precipitation, amount of snow cover, and temperature; and (c) soil properties, which include slope, permeability, and salt-retention capabilities.

The detrimental effects of de-icing salts to roadside vegetation are evident; however, public safety demands their use. Therefore, woody vegetation should be located as far from the highway as practicable with pavement drainage directed away from the tree roots. Where possible, the species planted should be chosen on the basis of salt tolerance and placed in a favorable medium.

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Sodium Chloride Uptake in Grasses as Influenced by Fertility Interaction

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ABRIDGMENT

•SODIUM CHLORIDE UPTAKE and distribution within plants differ among grass species. Apart from osmotic effects, the susceptibility or tolerance of grasses to salt is suspected to depend on the uptake, the distribution in plant tissues, and the accumulation of sodium and chloride causing ionic imbalances. Ionic imbalances can be caused by salinity-fertility interactions. The purpose of this investigation was to determine the relationships among rates of application of sodium chloride on absorption of sodium and chloride by grasses, growth, and content of sodium and chloride under fairly high fertility, and to determine the effect of complementary anions and cations in the rooting medium on sodium and chloride absorption.

Field and greenhouse experiments were conducted with sodium chloride to study the effects of de-icing salts on grasses along highways. Bromegrass (Bromus inermis), red fescue (Festuca rubia), Kentucky bluegrass (Poa pratensis L.), and Kentucky 31 fescue (Festuca arundinacea) were used in an experiment at Warsaw, Virginia, to compare the responses of these grasses with similar salt treatments. Rock salt was applied at rates of 2, 4, and 6 tons/acre in 6 split applications during the winter months of 1967-68 on all grasses seeded in 1966. In the early spring, 50 lb/acre of nitrogen was applied on half of each plot. The grasses were harvested in June and analyzed for sodium and chloride.

Salinity-fertility interactions were investigated in additional experiments with Kentucky 31 fescue in the field and with corn in the greenhouse. The plants were grown at different fertility levels after which a salt treatment was applied.

There was a close relationship between rates of applying the de-icing salt and amounts of sodium and chloride absorbed by grasses (Table 1). With increases in rates of application, there were corresponding increases of sodium and chloride in plant tissues. Chloride content in tissue was several times higher than sodium. Simple linear regression analysis showed highly significant relationships between sodium and chloride applied and contents in tissues, indicating that salt treatments were responsible for sodium and chloride absorption by fescue. Approximately 80 to 90 percent of the sodium and chloride in tissues was attributed to the salt treatment.

Increasing increments of rock salt retarded growth of the grasses studied (Table 2). This retarded growth may have contributed to the high contents of sodium and chloride in tissues. Additional studies in the greenhouse on these same grass species showed that the yield depression was more severe for tops than for roots. Of 4 grasses investigated, Kentucky 31 fescue maintained good ground cover even at 4 and 6 tons of sodium chloride per acre. Nitrogen treatments tended to minimize yield depressions due to sodium chloride. However, high rates of nitrogen tended to increase the absorption of both sodium and chloride.

A second field experiment with Kentucky 31 fescue (Table 3) shows the effects of potassium and nitrogen on uptake of sodium and chloride. Increased rates of potassium decreased the uptake of sodium, a highly significant sodium-potassium interaction. It appears that sodium uptake by grasses may be minimized by increasing the availability

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of potassium. Higher rates of nitrogen tended to increase absorption and concentration of sodium and chloride in tissues. Adding nitrogen and potassium increased the absorption of chloride and sodium but to a lesser extent than adding only nitrogen. There was little or no change in calcium and magnesium contents from rock salt treatments.

Sulfate, phosphate, and nitrate ions applied as sodium salts decreased the uptake of chloride but not sodium ions by corn seedlings (Table 4). Phosphate ions were more effective than sulfate. Sulfate, phosphate, and nitrate ions applied as salts of calcium and potassium also decreased sodium and chloride uptake. However, potassium salts were more effective than calcium salts. There was an inverse relationship between phosphate and chloride content of the tissue. As phosphate content in tissue increased, the chloride content tended to decrease. Also, potassium in soil tended to reduce sodium absorption. The results indicate that the use of potassium phosphate with de-icing compounds may be effective in decreasing sodium and chloride uptake, thereby minimizing salt injury.

TABLE 1

EFFECT OF RATES OF APPLYING SODIUM CHLORIDE ON THE CONTENT OF SODIUM AND CHLORIDE IN KENTUCKY 31 FESCUE TOPS

Rock Salt (ton/acre)	Percent Sodium Growth			Percent Chloride Growth		
	1st	2nd	3rd	1st	2nd	3rd
0.00	0.07	0.07	0.02	0.93	1.34	0.97
0.25	0.47	0.42	0.31	1.60	1.66	1.46
0.50	0.82	0.59	0.59	2.38	1.94	1.57
1.00	1.58	1.16	1.08	3.04	2.90	2.06
2.00	2.00	2.10	1.58	4.12	3.76	2.59
4.00	3.20	3.20	2.68	5.33	5.55	4.16

Note: Sodium and chloride contents are percentages of dry matter.

TABLE 2

EFFECT OF SODIUM CHLORIDE AND NITROGEN ON YIELD AND SODIUM AND CHLORIDE CONTENTS OF 4 GRASS SPECIES

Rock Salt (ton/acre)	Bromegrass			Red Fescue			Kentucky Bluegrass			Kentucky 31		
	Yield	Na	Cl	Yield	Na	Cl	Yield	Na	Cl	Yield	Na	Cl
Check	460	0.01	0.45	401	0.01	0.41	312	0.01	0.35	478	0.02	0.80
Check + N	527	0.01	0.58	460	0.01	0.47	338	0.01	0.59	513	0.02	1.20
RS 2	361	0.04	0.55	356	0.03	0.41	197	0.03	0.50	395	0.01	1.05
RS 2 + N	399	0.03	0.63	390	0.06	0.86	220	0.03	0.52	438	0.14	1.12
RS 4	180	0.04	0.60	147	0.03	0.53	100	0.03	0.41	207	0.17	1.13
RS 4 + N	225	0.05	0.81	177	0.05	0.70	144	0.09	1.15	260	0.03	1.58
RS 6	100	0.11	0.89	96	0.07	0.55	82	0.08	0.97	194	0.24	1.02
RS 6 + N	150	0.07	0.89	131	0.07	0.77	100	0.07	0.81	238	0.22	1.72

Note: Mean yield in grams per plot; sodium and chloride in percentage of dry matter of tops.

TABLE 3

EFFECT OF SODIUM CHLORIDE AT DIFFERENT FERTILITY LEVELS ON CHLORIDE, SODIUM, CALCIUM, MAGNESIUM, AND POTASSIUM CONTENTS OF KENTUCKY 31 FESCUE

Treatments[a] (lb/acre)	Percent of Tissue				
	Cl	Na	Ca	Mg	K
60N, 26P, 50K	0.73	0.04	0.36	0.02	1.72
60N, 26P, 50K + RS	2.08	0.92	0.34	0.18	1.40
160N, 26P, 50K	0.73	0.02	0.48	0.02	1.72
160N, 26P, 50K + RS	2.55	1.18	0.38	0.18	1.62
210N, 26P, 50K	0.85	0.04	0.36	0.02	2.05
210N, 26P, 50K + RS	2.87	1.42	0.41	0.02	2.00
60N, 26P, 100K	0.72	0.02	0.40	0.18	1.75
210N, 26P, 50K + RS	2.66	1.25	0.36	0.18	1.44
60N, 26P, 175K	0.60	0.03	0.33	0.20	1.42
60N, 26P, 175K + RS	2.25	0.95	0.35	0.20	1.50
60N, 26P, 300K	0.74	0.03	0.35	0.20	1.68
60N, 26P, 300K + RS	2.20	0.95	0.29	0.20	1.49
160N, 26P, 100K	0.72	0.02	0.39	0.20	1.68
160N, 26P, 100K + RS	2.34	1.10	0.31	0.18	1.72
210N, 26P, 175K	0.88	0.04	0.39	0.20	2.20
210N, 26P, 175K + RS	2.77	1.32	0.31	0.20	2.15

[a]N = nitrogen; P = phosphorus; K = potassium; RS = rock salt.

TABLE 4

EFFECT OF COMPLEMENTARY ANIONS AND CATIONS IN THE ROOTING MEDIUM ON THE UPTAKE OF CHLORIDE, PHOSPHATE, SODIUM, POTASSIUM, AND CALCIUM BY CORN SEEDLINGS

Treatments	Percent Dry Weight of Tissue				
	Cl	P	Na	Ca	K
Check	0.74	0.12	0.01	0.50	2.45
NaCl	2.24	0.12	0.03	0.50	2.03
NaCl + $NaSO_4$	2.20	0.12	0.02	0.51	1.73
NaCl + Na_2SO_4 + NaH_2PO_4	1.01	0.21	0.03	0.31	0.76
NaCl + Na_2SO_4 + NaH_2PO_4 + $NaNO_3$	1.01	0.24	0.04	0.26	0.61
NaCl + $CaSO_4$ + $CaHPO_4$ + $NaNO_3$	1.55	0.26	0.02	0.46	1.03
NaCl + K_2SO_4 + KH_2PO_4 + KNO_3	1.24	0.18	0.01	0.48	2.80
NaCl + Ca and K_2SO_4 + PO_4 + NO_3	1.48	0.17	0.01	0.46	2.07

There was a highly significant relationship between rates of applying rock salt and amounts of sodium and chloride in grass tops. Chloride accumulation in tissues was much higher than sodium. Sodium chloride depressed the top growth of grasses much more than the roots. Kentucky 31 fescue was more tolerant to sodium chloride than bromegrass, red fescue, and Kentucky bluegrass. Nitrogen minimized the yield depression and injury due to sodium chloride. However, high rates of nitrogen increased sodium and chloride absorption.

Potassium reduced sodium uptake of grasses. Phosphate ions reduced chloride absorption. Potassium phosphate was more effective in retarding chloride uptake than calcium phosphate. There was an inverse relationship between chloride and phosphate content in tissues. Hence, high soil phosphates should reduce chloride absorption.

These investigations show that there was less rock salt damage to plants with certain fertilizer salt nutrients than when rock salt was applied alone. Ions such as potassium and phosphates competed with and reduced sodium and chloride uptake, thereby improving plant survival. Before salt mixtures are used for de-icing, the effectiveness of salts as ice-melting agents, the costs of the material, and the polluting potentials must be considered.

Perhaps the most practical way to benefit from desirable fertilizer ions is to maintain a good soil fertility with roadside planting.

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Salt Tolerance of Trees and Shrubs to De-Icing Salts

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ABRIDGMENT

Studies in Virginia, Maine, Connecticut, and Massachusetts have called attention to the effects of de-icing salts on roadside plants. Even though these detrimental effects have recently attained importance, the areas along the roads affected are sporadic; and the total area is quite small compared to the large mileage of roads treated. Nevertheless, the continuous applications of large amounts of these salts will affect larger areas, and maintaining vegetation along roads will become more of a problem.

De-icing salts in soils are taken up by plants and cause leaf burn, premature defoliation, and terminal growth dieback. Salt damage is of concern because of unsightliness and added costs of removing or replacing the plants. The use of salt-tolerant plants is a realistic approach to maintaining vegetation in the problem areas. Salt tolerance is not a parameter commonly used when plants are selected for the humid area; nevertheless, it becomes increasingly more important when plants are selected for use along roads that receive large applications of salt, and especially where de-icing salts have been a problem.

The purpose of this paper is to summarize the findings of a study intended to determine the tolerance of several deciduous trees and shrubs and several evergreen trees and shrubs to the commonly used de-icing salts—sodium and calcium chlorides. A rapid and practical approach was employed where salt tolerance was based on plant injury symptoms and survival after salt treatment under field conditions.

The field experiments with deciduous and evergreen trees and shrubs were established in the spring of 1966 in 3 physiographic regions of Virginia: mountains at Blacksburg, piedmont at Orange, and coastal plain at Warsaw. The soils on which the 3 sites were located were Groseclose, Nason, and Sassafras respectively. A planting plot design was used that allowed for 12 different salt treatments over whole plots. Within each whole plot 6 species were planted as bare-root seedlings in random rows of 9 plants on 3-ft centers. All treatments were replicated 4 times, except that treatments for the deciduous shrubs at Blacksburg were replicated 3 times. Salt treatments consisted of rates of sodium chloride up to 6 tons and calcium chloride up to 3 tons applied in the solid form as split applications during the winter months.

Salt-tolerance ratings of the species were based on a numeral scale as follows: 1, healthy; 2, slight leaf scorching; 3, moderate leaf scorching and slight defoliation; 4, severe leaf scorching, moderate defoliation, and minor limb dieback; and 5, severe defoliation, extreme limb deterioration, and plant dead or dying. A sixth rating class was added to the tolerance ratings the second year to account for the plants that died after ratings were taken on the first salt treatments. Ratings for the salt-treated plants were compared with those of the untreated plants.

Table 1 gives the average salt tolerance ratings across all salt treatments. The letters represent statistical differences, and the rating values that have common letters do not differ significantly. Thornless honey locust was tolerant to either sodium chloride or calcium chloride and survived all treatments. These plants remained healthy,

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TABLE 1

AVERAGE SALT-TOLERANCE RATINGS ACROSS ALL SALT TREATMENTS

Species	May 1967		August 1968		
	Blacksburg	Warsaw	Blacksburg	Warsaw	Orange
Deciduous trees					
Green ash (Fraxinus pennsylvanica)		3.6c		3.6c	3.6c
Sugar maple (Acer saccharum)	3.5c	2.9b	3.8c	2.6b	2.5b
White birch (Betula pendula)	3.0b	3.0b	2.7b	2.7b	1.7a
Thornless honey locust (Gleditsia triacanthos inermis)	1.8a	1.6a	2.1a	2.2a	1.8a
Tulip poplar (Liriodendron tulipifera)	4.5c	4.0d	5.3d	4.2d	4.0c
Redbud (Cercis canadensis)	3.9d	3.0b	4.1c	2.9b	2.6b
Deciduous shrubs					
Tartarian honeysuckle (Lonicera tartarica)	2.1a	2.4b	2.0a	2.4a	1.6a
Spring glory forsythia (Forsythia intermedia spectabilis)	2.8b	2.7b	3.3b	3.3b	1.4a
Spirea (Spirea Vanhouttei)	4.0d	3.5d	4.1c	4.1c	2.2b
Amur privet (Ligustrum amurense)	1.9a	2.1a	2.0a	2.1a	1.4a
Red-flowered weigela (Weigela Eva Rathke)	3.6c	3.0c	3.8bc	3.3b	1.7a
Rose (Rosa multiflora)	4.1d	3.6d	4.1c	3.5c	2.6c
Evergreen trees and shrubs					
Creeping juniper (Juniperus horizontalis plumosa)	3.1b	2.6b		2.8b	
Pfitzer juniper (Juniperus chinensis pfitzeriana)	2.3a	1.9a	2.0a	2.0a	
Adam's needle (Yucca filamentosa)		3.0c		1.8a	
White pine (Pinus strobus)	3.2b	3.3d	3.1b	3.7c	
Norway spruce (Picea abies)	3.5b	3.6de	4.0c	4.7d	
Canadian hemlock (Tsuga canadensis)	4.5c	3.7e	5.2d	4.9d	

even for the highest salt treatments, during the duration of the 4-year experiment. White birch, sugar maple, and redbud were moderately tolerant, but there was serious injury on the plots with high salt rates; and many of these plants failed to survive during the summer following the first winter treatments. Green ash and tulip poplar were injured by both salts. Injury occurred at the low salt application rates; the higher salt rates killed most of these 2 species. Many of the green ash and tulip poplar trees died during July and August the first summer after salt treatments. Green ash was not reported for the mountain area because it was planted in the late fall to replace another species, and poor survival was obtained. The late planting and small size of the trees when treated with salt may have contributed to the susceptibility of green ash.

Privet and honeysuckle survived all salt treatments and were most tolerant among the 6 species. Forsythia and weigela were intermediate, while spirea and rose were sensitive to both sodium and calcium chlorides. Privet and honeysuckle showed little or no damage and had no visible leaf-burn symptoms. Frequently, spirea was seriously injured, showing complete leaf drop and dead woody tissue. The salt tolerance of the plants tended to increase with age and growth; similar salt treatments produced more injury when applied on the small young plants. The rating values showed less salt injury for the Orange location as compared with the other 2 areas. This difference in plant ratings may well be an expression of salinity-fertility interaction because Nason is a very poor soil.

The 6 evergreen species can be divided into 2 groups: 3 salt-tolerant and 3 salt-sensitive plants. The salt-tolerant group included pfitzer juniper, creeping juniper, and Adam's needle. White pine, Norway spruce, and Canadian hemlock were very sensitive to the salts. During the first winter, even the lowest salt rates seriously

injured and frequently killed these less tolerant species. The 3 salt-sensitive species were so injured by the low salt rates that they did not survive the first summer, yet the salt-tolerant group remained healthy. Pfitzer juniper and Adam's needle even survived the highest salt rates. Because of poor survival at the Blacksburg location, Adam's needle was not included in the experiment and creeping juniper was excluded the second year. The degree of injury for individual species was dependent on whether sodium chloride or calcium chloride was applied. It was observed in August 1969 that a 3-ton treatment of these salts showed calcium chloride to cause more injury to white pine, while sodium chloride caused more injury to hemlock.

The plants studied gave significant differences in response to salt treatments, and species-salt treatment interactions were observed. Plants that were sensitive to the 2 de-icing salts showed increasing degrees of leaf burn, leaf defoliation, and limb dieback as the amount of salts applied increased. The more tolerant plants such as honey locust, honeysuckle, privet, and pfitzer juniper showed no leaf burn, even for the highest salt-treatment rates.

The average tolerance values across all sodium chloride and calcium chloride treatments showed salt tolerance of the deciduous trees to increase in the following order: tulip poplar < green ash < redbud = sugar maple $\overline{<}$ white birch < honey locust. For the deciduous shrubs salt tolerance increased in the following order: rose = spirea < weigela $\overline{<}$ forsythia < honeysuckle $\overline{<}$ privet. Salt tolerance for the evergreens increased in the following order: hemlock < Norway spruce < white pine < creeping juniper < Adam's needle $\overline{<}$ pfitzer juniper.

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Establishing Crown Vetch on Steep Acid Slopes in Virginia

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There is a critical need for persistent vegetation with low maintenance costs for steep roadside slopes. Crown vetch (Coronilla varia) is one such leguminous plant that is adapted to many environments. Experiments in Appalachian, Blue Ridge, and Piedmont regions of Virginia were conducted to investigate effects of lime, nitrogen and phosphorus fertilizers, companion grasses, establishment methods, and slope exposure on growth, establishment, and persistence of crown vetch. Crown vetch seedlings developed slowly the first year and generally required 2 to 3 years to provide a complete ground cover. Agricultural limestone at 2,000 to 4,000 lb/acre or hydrated lime at 1,000 to 2,000 lb/acre substantially improved survival and seedling growth of crown vetch at all locations; 100 to 200 lb/acre of P_2O_5 gave additional responses but high rates (150 lb/acre) of soluble N generally overstimulated growth of Kentucky 31 tall fescue and other companion grasses that retarded crown vetch seedings and subsequent stands. Applying 50 to 75 percent nitrogen per acre as slow-release nitrogen (ureaformaldehyde) provided stable and less aggressive companion grass growth and permitted satisfactory crown vetch establishment. Best crown vetch seedling stands and first winter survival were obtained with early spring seedlings. More uniform and faster ground cover was obtained on the cooler semi-shaded slopes than on sunny slopes. Satisfactory stands were obtained with root cuttings, but this establishment method was more costly than that of seeding. Stands of crown vetch on slopes, limed and fertilized liberally at establishment, have persisted without additional lime and fertilizer for 12 years.

• MODERN ROAD CONSTRUCTION in areas of steep topography causes many steep slopes. In the humid eastern United States, such steep slopes generally consist of infertile, acid, and droughty soil materials.

It is practical to seed vigorously growing grasses on highway slopes for fast slope stabilization and water control, but grass vegetation even with high initial fertilizer applications soon degenerates because soil materials are low in organic matter and available nitrogen. Applying topsoil and slow-release nitrogen improves grass persistence but at high costs. The encroachment of natural woody vegetation into thinning grass sods is very desirable; however, grass degeneration is often rapid causing bare, unsightly, and eroding slopes. Leguminous plants that are persistent and fix atmospheric nitrogen into usable nitrogen are especially desirable. Crown vetch (Coronilla varia) and sericea lespedeza (Lespedeza cuneata) are 2 such persistent legumes; crown vetch with lateral rooting plants that spread into adjacent bald areas and into thinning vegetation is very desirable (3).

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Observations along Interstate and other highways in Virginia show thinning of many grass sods on steep slopes soon after establishment. A long-lasting slope stabilization can be obtained by using maintenance fertilizers or by grass-legume seed mixtures where the grassy vegetation shifts to persistent leguminous soil cover. Several experiments were conducted in Virginia to determine the adaptation and the feasibility of using crown vetch on roadside slopes for obtaining persistent and low maintenance vegetative cover.

This is a review of research findings during 12 years of establishing crown vetch on bare slopes and overseedings in thin grass sods. This report gives research results on slope environment, liming, fertility, seeding rates, seed treatments, and grass associates on establishing and maintaining crown vetch.

EXPERIMENTAL PROCEDURES

Since 1957, several experiments with crown vetch were conducted in the Appalachian, Blue Ridge, and Piedmont regions of Virginia to determine general adaptability of crown vetch to various soil materials and slope environments. Experiments were established as new seedings on bare slopes and also on slopes where the grass sods had degenerated to less than 75 percent ground cover.

The treatment variables with crown vetch establishment and maintenance were (a) rates of lime application, (b) sources of lime materials, (c) methods of fertilization, including rates of nitrogen and phosphorus, (d) dates of seeding, (e) companion grass mixtures, (f) fungicidal treatment of seed to control seedling diseases, and (g) methods of management. Seed of the Penngift and Emerald varieties was used in most of the experiments, and 4 experiments were conducted with crown root stocks. Seed mixtures for new seedings consisted of 40 to 50 lb of Kentucky 31 fescue, 1 to 2 lb of redtop, and 5 to 8 lb of annual ryegrass per acre; and most new areas were fertilized with a 10-20-10 fertilizer at 1,000 lb/acre.

Because many different experiments are involved in this summary report, the details are excluded. Standard research procedures with 2 to 4 replications per treatment variable for statistical analysis were used.

RESULTS AND DISCUSSION

Seedling Growth and Responses to Slope Environment

Germination and seedling growth of crown vetch plants were relatively slow in comparison to most cool-season, sod-forming grasses and other legumes. The first season's growth generally consisted of one central and multi-branched primary stem and contributed little to the turf cover; however, tap and lateral root development were more extensive during this period (Fig. 1). Near the end of the first year, buds formed in crowns and lateral roots formed near the soil surface. The second year's growth from these buds was vigorous, causing extensive and rapid spreading, especially rapid with limited competition from other plants.

Because of slow initial seedling development, crown vetch should be seeded with companion grasses to provide temporary soil cover during the first year or two. Initial sparse stands of crown vetch develop rapidly into dense soil cover under suitable soil environments and microclimates (Fig. 2).

Good crown vetch stands are being obtained on warm and cool slopes. However, seed germination and seedling growth are much faster for cool-slope sites (2). The higher temperatures and lower moisture retard crown vetch establishment on slopes having sunny exposures as compared with those having shaded exposures.

Lime and Fertility Responses on New Bare Slopes

Results of several experiments on different acid soil formations show that satisfactory crown vetch seedling growth, establishment, and maintenance depend on adequate liming. Except for limestone or shalely limestone soil materials above pH 6, lime is essential for establishing crown vetch. For acid soils of limestone origin, there

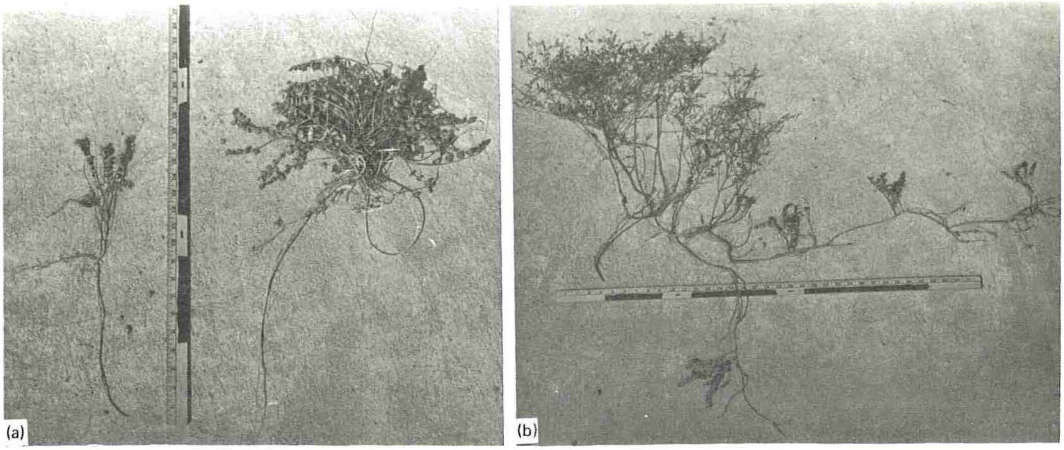

Figure 1. Morphological changes in crown vetch between the first year (a) and the second year (b). Note lateral spread after 2 years.

was improved seedling survival, faster growth, and more lateral spread with 1 to 2 tons of dolomitic lime per acre than with no lime. Crown vetch seedling growth was almost completely inhibited on very acid soils, especially on southern piedmont soils that are high in exchangeable aluminum (Table 1). Such soil characteristics along with moisture stress and competition from other plants cause a high incidence of crown vetch seedling mortality and stand failures.

For 3 experiments on acid soil formations in the Piedmont region of Virginia, crown vetch failed to develop stands without lime (Table 1). These experiments were established on Cecil subsoil slopes (geologically granitic materials) that were very acid with pH's ranging from 4.1 to 4.7. Associated with the high acidity of these soils was high exchangeable aluminum (2.2 to 2.9 meq of KCl extractable Al per 100 grams of soil). Calcium contents were very low for all 3 soils being less than 180 lb of CaO per acre.

A greenhouse experiment showed near complete failure of crown vetch seedlings in the absence of lime. Lime applied at 2,000 or 4,000 lb/acre improved survival and

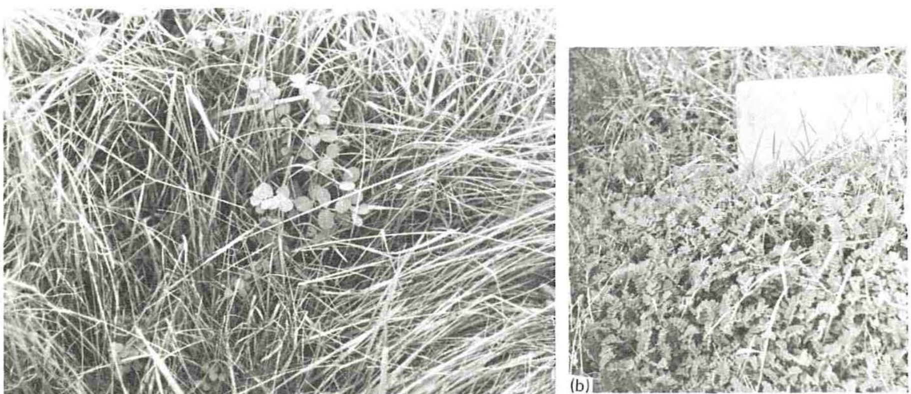

Figure 2. Crown vetch seedling development in grass stands 6 months after seeding (a) and 30 months after seeding (b).

TABLE 1

CROWN VETCH SEEDLING GROWTH RESPONSES ON SEVERAL APPALACHIAN AND PIEDMONT SOIL FORMATIONS AS INFLUENCED BY pH, EXCHANGEABLE ALUMINUM CONTENT, AND LIME TREATMENTS

Soil Formation	Initial pH	Exchangeable Aluminum (meq/100 g soil)	Crown Vetch Ground Cover (percent)					
			No Lime			4,000 lb Ground Lime per Acre		
			1st Year	2nd Year	4th Year	1st Year	2nd Year	4th Year
Piedmont								
Lynchburg	4.7	2.8	—[a]	5	—[a]	5	—[a]	70-80
Amelia	4.1	2.2	—[a]	5	—[a]	5	—[a]	100
Martinsville	4.7	3.1	—[a]	—[a]	5	—[a]	—[a]	60-100
Appalachian								
Salem	5.2	0.2	5	10-20	50-100	5	—[a]	100
Blacksburg	4.8	4.3	—[a]	5	5-10	5	40-50	100
Pulaski I	5.3	0.3	5	10-20	30-50	5	30-60	100
Pulaski II	6.2	0.1	5	10-20	40-60	5-10	25-60	100
Chilhowie	4.9	1.1	5	5-25	35-75	5-10	75-100	100

[a]Estimates were not determined.

growth of crown vetch plants in a greenhouse experiment. The very poor growth of crown vetch seedlings was attributed to a complex of high soluble aluminum, low calcium, and low phosphorus, which appeared to be fully alleviated by applying 1 to 2 tons of agricultural limestone and 200 lb of P_2O_5 per acre (4).

On limed plots the first year, Kentucky 31 fescue and annual ryegrass made up about 95 percent of the soil cover with a few crown vetch plants making up the remainder. However, by the third year, a complete botanical shift from grass to crown vetch vegetation had occurred. On unlimed plots, crown vetch failed to establish, and the grass vegetation degenerated rapidly. Five years after initial establishment, the entire area of one experiment was limed and given additional superphosphate. In this experiment, crown vetch from plots originally 12 ft wide have now spread laterally 40 to 60 ft.

For 3 common acid Appalachian soil formations, liming did not appear to be critical for crown vetch seedling survival; however, liming improved seedling growth and rate of establishment (Table 1). In 4 such experiments, crown vetch was seeded with Kentucky 31 fescue that had received 1,000 lb of 10-20-10 fertilizer per acre. Because of liberal nitrogen applications, the initial soil cover consisted of nearly 100 percent grass with very few crown vetch plants the first year. On limed plots the grassy vegetation shifted to crown vetch by the second and third year. On unlimed plots, crown vetch cover increased slowly but did not give a complete cover by the fourth year as with the limed plots. These soils were generally less acid and contained less exchangeable aluminum than the Piedmont soils (Table 1). However, exchangeable aluminum was quite high (4.3 meq/100 g soil) in the soil formation at Blacksburg, and liberal liming was necessary for satisfactory establishment.

The differential growth and establishment responses with lime for Appalachian and Piedmont soils may be attributed to several factors: (a) The Appalachian soil formations of limestone origin were generally moderately acid (pH 4.7 to 5.5) and higher in calcium (197 to 385 lb of CaO per acre) than the Piedmont soils; (b) there were no appreciable amounts of exchangeable aluminum in the 4 Appalachian soils, although one Appalachian soil was quite high in exchangeable aluminum (4.5 to 5.1 meq/100 g soil); and (c) slope environments in the mountainous Appalachian region were cooler during spring and summer months and were more favorable for seedling growth.

Nitrogen Fertilization and Companion Grass Competition

The slow germination and seedling growth of crown vetch necessitate using companion species to give a quick vegetative cover for slope stabilization during establishment. However, the vigorously growing grasses, such as ryegrasses and tall fescue, compete aggressively for light, moisture, and soil nutrients. Consequently, the initial crown vetch development is often greatly depressed (4). Sowing rates of grasses and rates

of nitrogen fertilizers must be carefully manipulated to provide stable cover but not excessive growth.

It is necessary to establish a dense grass cover quickly for soil and water control, especially on steep slope sites. To get such a sod cover, around 100 lb of nitrogen per acre along with liberal seeding rates is required. By applying some of the nitrogen as slow-release nitrogen, the initial aggressiveness of grasses toward crown vetch can be partially alleviated.

An experiment near Blacksburg, Virginia, was conducted to investigate seedling competition and nitrogen requirements for establishing crown vetch with perennial grasses in Virginia. The nitrogen treatments of water-soluble nitrogen were (a) 75 lb/acre; (b) 150 lb/acre; (c) 75 lb/acre plus 400 lb of ureaformaldehyde per acre; and (d) 75 lb/acre at seeding plus 75 lb/acre 1 year later. The initial vegetative cover was primarily annual ryegrass with 10 to 20 percent Kentucky 31 fescue. The stands of crown vetch were severely reduced as nitrogen was increased from 75 to 150 lb/acre (Fig. 3). This effect was severe during the first year but began to diminish by the following spring. The grass cover with 75 lb of soluble N was inferior to that with 150 lb of N and not satisfactory for soil and water control during the second year (Fig. 4). Applying 150 lb of nitrogen per acre as ureaformaldehyde and 75 lb of soluble N gave good crown vetch stands and satisfactory turf cover during the first 3 years. Applying split applications of soluble N (75 lb per application) the first and second year stimulated grass growth the second year and caused severe crown vetch stand losses (Fig. 3). Figure 5 shows the erosion rates the second year after seeding.

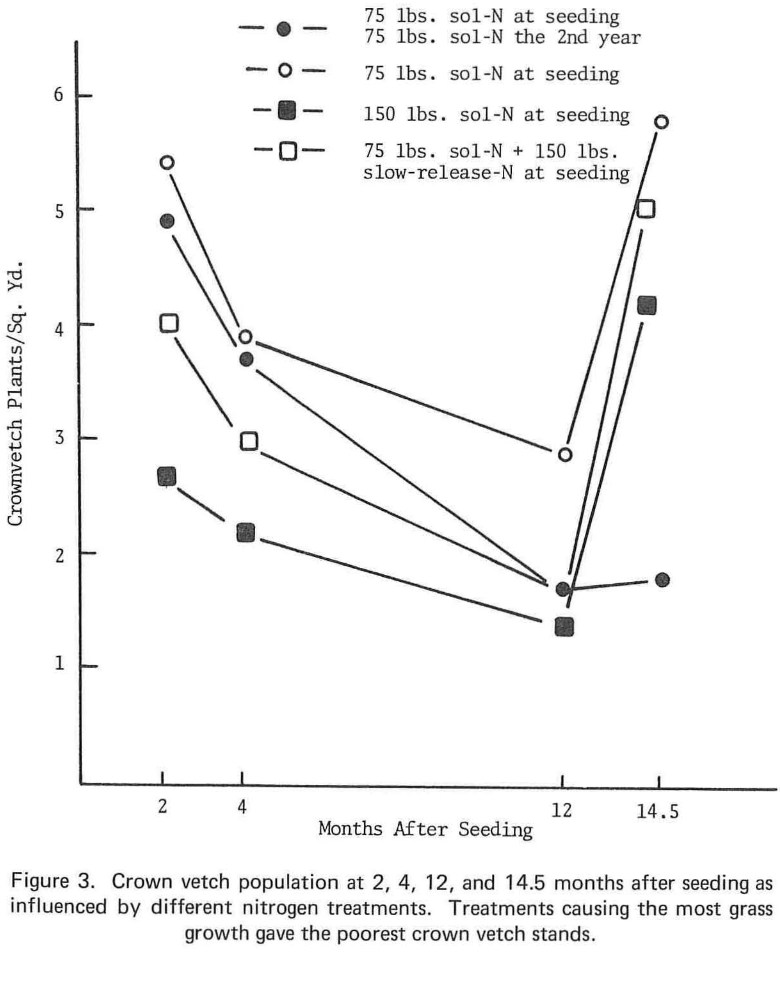

Figure 3. Crown vetch population at 2, 4, 12, and 14.5 months after seeding as influenced by different nitrogen treatments. Treatments causing the most grass growth gave the poorest crown vetch stands.

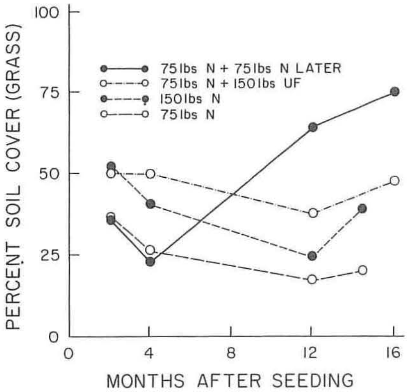

Figure 4. Ground cover for an annual ryegrass-Kentucky 31 tall fescue-crown vetch mixture at 4 to 16 months after seeding as influenced by nitrogen rate, source, and frequency of application.

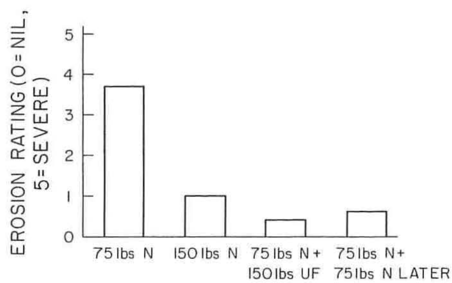

Figure 5. Erosion ratings the second year after seeding for an annual ryegrass-Kentucky 31 tall fescue-crown vetch mixture as influenced by different N rates, sources, and frequency of application.

Companion Grasses

Suitable companion grasses for establishing crown vetch should provide fast soil cover and erosion control and persist at least 2 to 3 years. The best type of companion grass to grow during crown vetch establishment is questionable.

Seeding crown vetch with annual ryegrass has given variable success. With such seedings the growth and development of crown vetch were delayed until after the first year or after annual ryegrass competition ceased. The dead stubble of the annual ryegrass made an excellent mulch for crown vetch seedlings, but stands were uneven and there was considerable slippage and erosion. These areas became stabilized in subsequent years as the crown vetch encroached.

Low seeding rates of redtop with annual ryegrass have given stable ground cover the second year and uniform crown vetch establishment in several Virginia seedings.

Excellent crown vetch stands have been obtained with Kentucky 31 fescue in many of the experiments. Stands of crown vetch have also been very good with 3 to 5 lb of weeping love grass per acre. The erect growth of weeping love grass permits considerable light penetration into the canopy; also, crown vetch starts earlier spring growth than the warm-season love grass.

Overseeding Crown Vetch on Degenerating Grass Slopes

Degeneration of grass sods soon after establishment is a problem along Virginia highways. Grasses require available nitrogen for growth and persistence. The degeneration and sparse grass stands may be fertilized to give dense cover. Alternatives are to allow the encroachment of native vegetation on such microenvironments. Unfortunately, such botanical shifts do not accur uniformly, especially in open areas far from seed plants. Often noxious or weedy plants also encroach into such thinning grass sods.

Seeding and establishing legumes in deteriorating grass sods appears to be an excellent way of stopping further erosion and providing permanent soil cover on slopes. Several experiments were conducted to determine ways to establish crown vetch in deteriorating grass vegetation.

Ideally, grass slopes should be overseeded when there is a 35 to 45 percent ground cover so grasses control erosion while crown vetch becomes established. Such a grass cover generally controls erosion for an additional 2 to 3 years while legumes become established. On such slopes, companion grasses, N fertilizer, mulch, or soil preparation are not required.

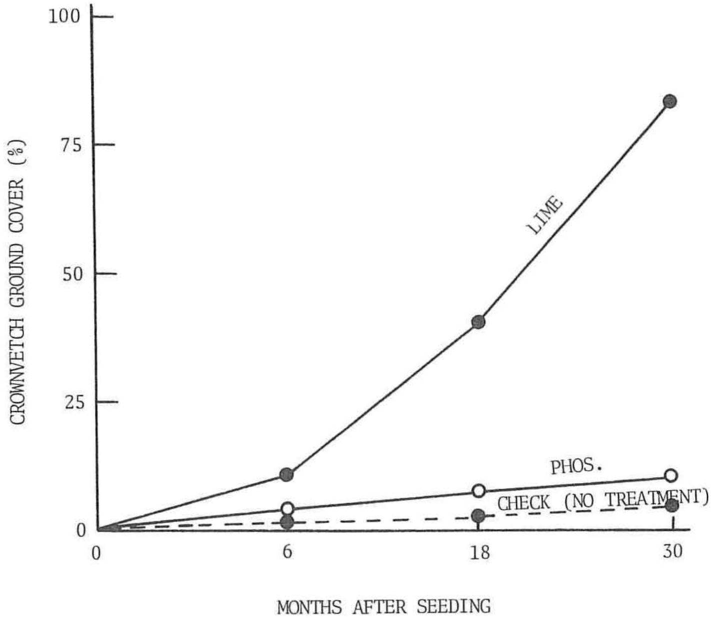

Figure 6. Crown vetch ground cover at 6, 18, and 30 months after seeding as influenced by 100 lb of P_2O_5 on 4,000 lb of dolomitic lime per acre. Seeding is on an old deteriorated grass slope near Marion, Virginia.

Two experiments on a 2:1 cut slope of Dunmore silt loam soil where the grass sod had degenerated to a 35 percent cover on the I-81 approach near Chilhowie shows that 3,000 lb of finely ground limestone or 1,500 lb of hydrated lime per acre greatly improved crown vetch establishment (Figs. 6 and 7). Initially, the crown vetch populations were similar for lime or no lime treatments. However, without lime, most of the crown vetch seedlings did not develop beyond the cotyledon stage; most of these turned yellow and died during the first year as evidenced by greatly reduced populations without lime at the end of the first growing season (Table 2). Plants on limed plots grew 4 to 8 in. in height during the first year but contributed little to the ground cover. These plants produced 24 to 40 percent ground cover the second year and 70 to 100 percent ground cover by the third year.

Applying up to 150 lb of phosphorus (P_2O_5) in addition to liming also improved crown vetch establishment (Figs. 6 and 7). Phosphorus alone (without lime) improved crown vetch populations only slightly and did not promote satisfactory development of crown vetch seedlings. This area had been fertilized with 1,500 lb/acre of 10-20-10 fertilizer 4 years prior to these experiments. The minor responses from phosphorus are attributed to the phosphorus availability from the residual fertilizer. It is

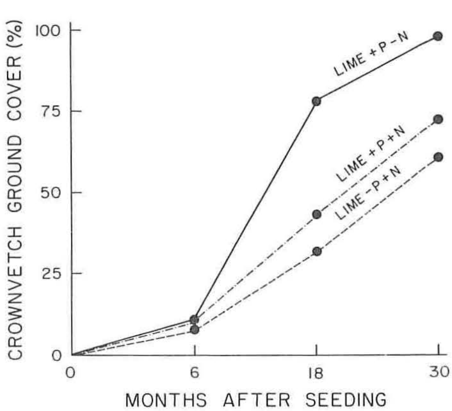

Figure 7. Crown vetch ground cover at 6, 18, and 30 months after a 1967 spring seeding as influenced by combinations of lime, phosphorus, and nitrogen. Rates of application were 4,000 lb of dolomitic lime, 100 lb of P_2O_5, and 50 lb of soluble nitrogen per acre.

necessary to apply phosphorus on all subsoil and most of the topsoil materials to grow legumes and grasses on bare-slope areas that have not been fertilized. The need to apply phosphorus on slopes that have been seeded depends on the amount applied, sheet erosion, and soil chemical properties. Soil tests should be made to ascertain the need to apply lime and phosphorus.

The effect of nitrogen fertilization on establishing crown vetch on slopes with poor cover was variable depending on the amount of ground cover. Nitrogen at 50 lb/acre augmented grass growth. When there was only a 15 to 20 percent ground cover, N fertilizer produced a more stable grass cover that indirectly aided crown vetch establishment. However, where a 35 to 40 percent grass cover remained, N fertilizer overstimulated grass growth that delayed crown vetch establishment because of light and possibly moisture competition.

TABLE 2

CROWN VETCH ESTABLISHMENT AS INTERRELATED TO LIME, NITROGEN, AND PHOSPHORUS TREATMENTS FOR MAY 1968 SEEDINGS

Date	N or P (lb/acre)	Plant Density (plants/sq yd)		Plant Height (in.)	
		Lime	No Lime	Lime	No Lime
8-1-68	Check	8.2	9.4	1.0	0.7
	50N	6.6	5.3	2.8	0.8
	$100P_2O_5$	9.0	8.2	1.7	0.8
	50N, $100P_2O_5$	8.1	7.4	3.1	1.1
6-9-69	Check	1.65	0.15	6.0	1.2
	50N	3.75	0.83	6.3	2.0
	$100P_2O_5$	5.33	2.15	4.2	3.2
	50N, $100P_2O_5$	4.00	2.98	5.4	2.6

Note: All N water soluble from ammonium nitrate.

Effects of Seeding Date, Seeding Rate, and Slope Exposure on Initial Establishment

Some research in other states indicates that crown vetch can be seeded any time of the year (5). In Virginia, the best uniform crown vetch stands have been produced from late winter and early spring seedings. Late spring and summer seedings have given lower populations and poorer seedling growth the first year. Plants germinating in early spring develop faster during the cooler spring months; however, during summer months, when temperature and moisture are often adverse, young seedlings develop little until fall months.

Many of the young plants with late summer and fall seedings do not survive the first winter. Data from an experiment near Blacksburg indicate a direct relation between plant height and first winter survival (Figs. 8 and 9). For this late summer seeding, about 42 percent of the seedlings were 1 in. or less in height by winter time; about 90 percent of these seedlings died during the winter (Fig. 9). As plant size increased to 4 in. before winter, the percentage of winter survival increased sharply to about 81 percent. The average winter survival for all seedlings on a south-facing slope for this late sowing was 39.5 percent.

Seedlings from early spring germination grow to sizable plants the first year and consistently grow better the following year than summer or fall seedings. Similar results were observed from fall and spring seedings made by personnel of the Virginia Department of Highways. However, fall seedings have also produced satisfactory stands because a few small plants survive and many hard seeds continue to germinate for some years after the initial seeding.

The higher percentage of winter survival of larger plants may be partly attributed to better developed roots and crown buds. Such seedings are more tolerant of low temperatures and soil heaving during the first winter.

Seed Treatments and Rate of Seeding

Washing seeds with water, mechanical scarifications, and fungicide treatments greatly improved crown vetch germination and seedling growth in greenhouse and laboratory studies; however, under roadside conditions these treatments only gave slight improvements in initial stands and did not improve rate of crown vetch establishment. Actually, some delayed crown vetch germination is desirable because many of the fast germinating seeds may be exterminated by aggressive grasses when high rates of grasses and nitrogen fertilizers are used for attaining quick soil cover.

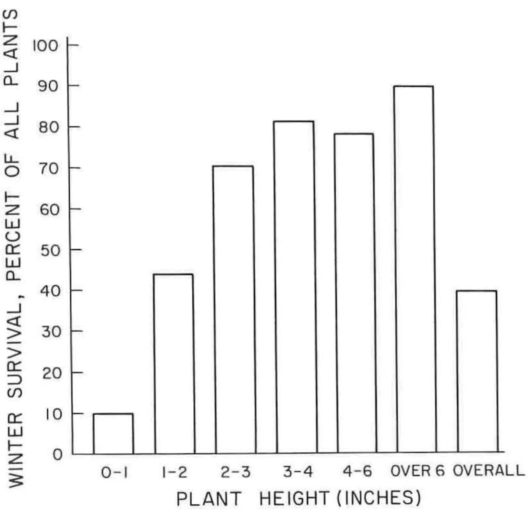

Figure 8. Winter survival of crown vetch seedling plants from an August seeding as related to plant height or size.

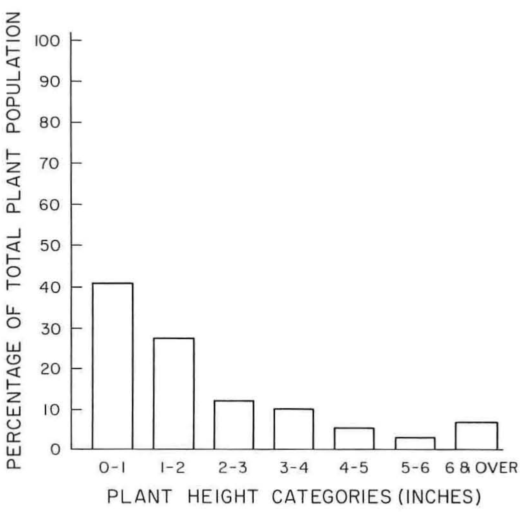

Figure 9. Crown vetch population in the different height categories for August seeding (data taken in late fall).

Seeding rates of 12 lb/acre produced good crown vetch stands and as fast as seeding at 24 lb/acre. Seeding rates of 10 to 12 lb have generally been satisfactory for establishing crown vetch. Excellent seedling stands are not needed because crown vetch spreads very rapidly after the seedling year.

Establishing Crown Vetch With Root Cuttings

Three experiments were established on slopes along Virginia highways near Blacksburg, Orange, and Charlotte Court House, Virginia, in 1958 to compare the effectiveness of seeding versus planting root cuttings for establishing crown vetch. The warm and cool cut slopes along Route 114 near Blacksburg were initially seeded in 1956. Crown vetch root stalks were planted in 4- by 4-in. spacings during the spring of 1958. At this time, there was a 50 percent cover on the warm slope exposure and a 75 percent cover on the cool slope exposure. The main variables were methods of planting the root cuttings. These were (a) planting the root cuttings with a soil probe in existing grass, and (b) destroying the grass sod in a 12- by 18-in. area and cupping it to catch moisture. The grass competition was severe, and the first method gave very poor survival and crown vetch stands; the latter method gave good survival and developed good crown vetch stands within 3 years. Watering did not improve stands because rainfall was abundant after planting. Stands and spread were much better on cool slopes than on warm slopes.

Similar experiments were established with root stocks in the Piedmont region of Virginia. Half of each plot received 10 lb of crown vetch seed per acre. A good stand was obtained on all plots, but the stand developed more rapidly on the seeded half of the plots.

Although good crown vetch stands were obtained with root cuttings, this procedure was costly and the rate of obtaining cover was no faster than with seed.

Management of Crown Vetch on Sunny and Shaded Slopes

Crown vetch has persisted for up to 12 years in Virginia and has not required maintenance, lime, and fertilizer with liberal initial applications. Weeds generally have not encroached into crown vetch stands.

Crown vetch is tolerant of mowing, although regrowth is slow after close cutting of tall crown vetch herbage. The effects of mowing were observed at most of the experiment sites as the basal section of the slope was mowed to keep the drainage ditch clear. Where crown vetch was grown with Kentucky 31 fescue, initial stands were primarily fescue but are now generally more than 80 percent crown vetch when unmowed. Slope sections mowed several times yearly are about half vetch and half fescue.

In the presence of sericea lespedeza, areas mowed 2 or 3 times annually have very little lespedeza but the stand of crown vetch is excellent. Sericea is most competitive toward crown vetch on unmowed areas because of its upright growth characteristics.

In the competition between crown vetch and sericea seeded together, crown vetch usually dominates on cool or warm slopes if the subsoil materials are high in calcium. Sericea lespedeza is more aggressively competitive toward crown vetch on warm than on cool slopes. On infertile soils, especially highly acid ones, sericea lespedeza becomes dominant. Crown vetch growth during the early spring season when sericea is dormant will finally shift the stands to crown vetch dominance under favorable soil and climatic environments.

SUMMARY

Stands of crown vetch are now persistent along Virginia highways on all geological soil formations in Virginia except the coastal plains where there has been little adaptive research. It may be established on new bare slopes or overseeded into slopes along highways where the grass sods have degenerated. Crown vetch is adapted best to the more northern and mountainous regions of Virginia, but stands have persisted without maintenance for more than 8 years in areas in the southern Piedmont on limed soils. The oldest stands have had little or no maintenance in 12 years.

This report is a research summary on establishing crown vetch for new seedings on bare slopes and on slopes where grass sods have degenerated. Lime, fertilization, rates and dates of seeding, grass associates, and seed treatments were investigated. Seedling morphology as related to spreading and the effects of mowing management is briefly discussed.

Personnel of the Virginia Department of Highways are obtaining successful stands of crown vetch in the southwestern region, and crown vetch is being specified in certain new contracts.

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Roadside Dry-Land Planting Research in Montana

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Dry-land planting of roadsides under semi-arid growing conditions is costly. The greatest potential in savings may be realized by reducing the cost of planting stock and the amount of handwork through mechanization. Two possible approaches seem logical to successful dry-land planting of adaptable species—either put roots down below the dry upper soil layer where the soil moisture is or bring the soil moisture up to where the root system is. The Montana Agricultural Experiment Station is investigating several systems, one of which is particularly well adapted to complete mechanization from nursery to roadside—the nurturing of seedlings in narrow but extraordinarily long tubes used as pots. Rooting response is a function of species, potting-soil texture sequence, and composition of the confining tube. Placing undisturbed roots of actively growing "tubelings" down in deep soil moisture reduces transplant shock, growth stagnation, need for irrigation, and maintenance. Advantages of tubelings in nursery production include reduced space requirements, quantity of soil, and labor and ease of transportation. Another approach to dry-land planting is the use of plastic-lined planting basins to reduce evaporation and to condense soil moisture. When the funnel-shaped liner is stretched and sealed over the basin and weighted near the exposed plant, condensate trickles downward toward the plant and irrigates it. The quantity of condensate is determined by soil moisture conditions, temperature differentials, liner color, soil texture and color, basin area, and leaks in the liner. Condensate collected beneath clear plastic liners exceeded that of black liners by three times. Only small quantities of water are necessary to maintain a small growing plant under evaporation-controlled conditions.

• SHRUB PLANTING on roadsides in the semi-arid portions of the western states is costly business, characterized generally by high mortality and very slow growth and development of stock. The evaporation potential commonly exceeds annual precipitation by several times in much of the area. Expensive irrigation systems have been installed in many major interchanges and rest stop areas, but often the alkaline salts contained in the deep well water make it unfit for prolonged irrigation purposes.

It is mandatory that more economical and effective systems be devised for providing permanent roadside vegetative cover. This may be accomplished in part by emphasizing the importance of species adaptation to prevailing growing conditions and by developing new dry-land seeding and planting methods. Research involving 2 new dry-land planting techniques will be included in this discussion; other promising possibilities are being investigated by the Montana Agricultural Experiment Station in cooperation with the Montana State Highway Commission and the Federal Highway Administration. However, materials and ideas within this report are those of the author and do not necessarily reflect the opinion or approval of the Montana State Highway Commission or the Federal Highway Administration.

Paper sponsored by Committee on Right-of-Way Maintenance and presented at the 49th Annual Meeting.

It is apparent that the greatest cost reduction in seedling tree and shrub planting could be achieved if one were to successfully increase the rate of plant survival, lower the high cost of planting stock, and reduce the amount of handwork now required by the usual standard planting processes. The implications of a planting method conducive to complete mechanization are tremendous, and the potential savings make it universally appealing.

Two possible approaches seem logical and essential to successful dry-land planting of adaptable species: either put the roots down below the dry upper soil layer so that soil moisture is directly available, or bring the soil moisture up to where the root system is. Both approaches and combinations of the two are currently being field tested. The systems described may appear radical, yet it is only the particular methods of utilizing and applying familiar principles that are new. One system is conducive to complete mechanization. Initial work has already eliminated some faults of the planting processes.

PLANTING SYSTEM 1

Deep-Tube Potted Plants

One departure from standard techniques, such as balled and burlapped or canned stock, utilizes a completely different concept of shrub materials production. It requires far less nursery space, soil, and labor, and facilitates handling and transportation of plant materials. This procedure involves the nurturing of seedling stock in small-diameter, long tubes used as pots in order to encourage development of narrow but extraordinarily deep root systems. Placing actively growing undisturbed roots within deep soil-moisture reserves eliminates the need for irrigation and extensive maintenance during the establishment period. It reduces transplant shock and growth stagnation.

Previous greenhouse work on the propagation of native shrub materials demonstrated root development of some species to be particularly well adapted to rapid longitudinal growth when planted in narrow but deep confining pots. Late spring planting of these native shrub seedlings after being removed from the impervious pots proved outstanding compared to standard stock.

This improvement in technique over regular procedures prompted attempts to develop extraordinarily long root systems. Plants were tested in decomposable pots 2½ in. in diameter by 2 ft deep. Approximately 2,000 tubes were filled with potting soil and planted with a variety of nursery stock in preparation for dry roadside testing (Fig. 1). These were called "tubelings" to distinguish them from standard control stock. They were kept in the greenhouse for as many as several months until roots reached the bottom of the 2-ft tubes.

A great deal was learned from the initial trials with tubelings. As the root development period progressed, it became more obvious that the composition of the potting tube was less than satisfactory, especially those tubes that were on the outside of grouped tubes as arranged on the greenhouse benches. Tubes within a dense grouping were continually damp and thus became gradually weaker as the root development period progressed, whereas exposed tubes remained dry, crisp, and impenetrable.

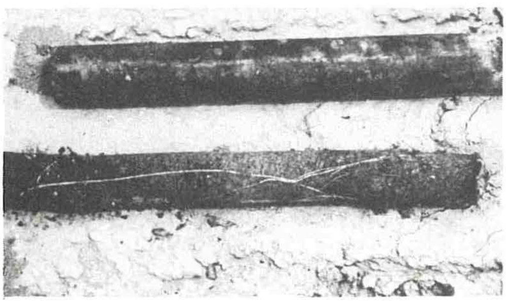

Figure 1. Tubeling with cover removed exposes extraordinarily deep root system developed within tube; species is common caragana (Caragana arborescens).

It became evident that the degree of success and speed of response in forcing deep root development were a compound function of species, potting-soil texture, and composition of the confining tube.

The arrangement of soils in sequence from a coarse sand at the top of the tubes to a fine silt loam at the bottom was found

essential in order to fulfill distinct requirements (Fig. 2). Percolation of water through the coarse top layer was rapid and expedited the watering process, yet an adequate reservoir was provided to catch sufficient moisture to dampen the tube to the bottom. A ½-in. lip above the soil surface provided a cup to catch water while sprinkling. Roots easily penetrated the upper coarser soils and moved into the finer soils below. The finer fraction of soils at the bottom retained moisture after the coarse surface soils dried out; this stimulated root growth downward. The finer soils at the bottom formed a dense soil plug that was necessary to prevent soil loss from the open bottom of the tube during transportation.

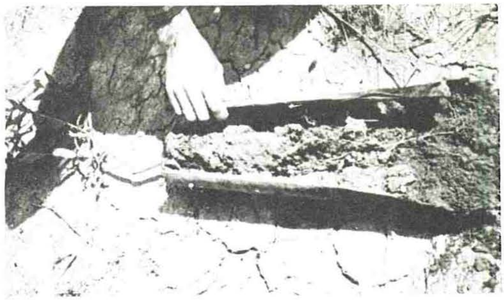

Figure 2. Sequence of soil textures ranged from a coarse sand at the top of the tube to a fine silt loam at the bottom to stimulate deep root development.

The search for a satisfactory material for a potting tube continues. Generally, materials found to be sufficiently strong to remain intact in a continuously damp condition through the several-month-long root development period are slow to disintegrate in the ground following planting. The need to remove resistant tubes, reusable tubes, and split metal or plastic tubes adds complications to the mechanized planting process. A tube of fine plastic mesh did not effectively contain the potting soil nor inhibit horizontal penetration of roots into adjoining tubes. These tubes proved to be unmanageable and very difficult and slow to fill. Recent investigations suggest that a rigid jute-composition tube reinforced on the outside with a high tensile ribbed plastic netting may be an effective combination at reasonable cost.

Several prunings of foliage during the root development period were necessary to keep top growth under control, to conserve growing space, and to reduce transpiration and foliage entanglement. Pruning of plant foliage, prior to loading for transport to the planting site, simplified the moving process. Likewise, it reduced foliage to an amount that a confined root system could reasonably support following planting under semi-arid conditions.

A hardening period of several weeks in a lathhouse preceding planting was necessary to prevent sunburning and to acclimate tender greenhouse-nurtured plants to desiccating winds, cold temperatures, and late spring frosts and snowstorms.

The transportation of tubed planting stock has been relatively free of problems. In a properly designed cradle, tubed plants may be placed horizontally and stacked as many as 15 plants high without any apparent damage. Approximately 300 plants of 2-year-old stock or equivalent stacked on the bed of a pickup truck have been hauled 250 miles to a planting site without damage or difficulty, but protection from wind is essential.

Initial planting of tubed stock was done with a hog-nosed tilling shovel; later a one-man gasoline-powered soil auger with a 2½-in. diameter bit was used. Drilled planting holes then received the 2-ft deep tubelings (Fig. 3). Air from around the tubes was removed, and essential soil contact was made with a prying action on the handle of a hog-nosed tiling shovel inserted around the tube at 3 positions several inches distant from each plant.

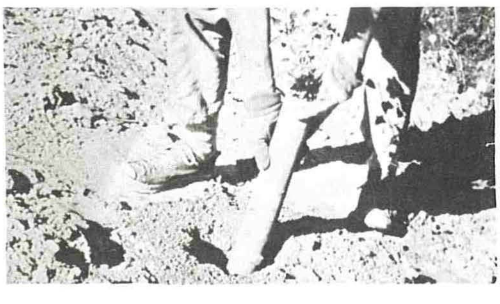

Figure 3. Tubelings are placed in planting holes drilled with a gasoline-powered soil auger, and air from around tubes is squeezed out and essential soil contact made by a prying action on the handle of a tilling shovel inserted around the tube at 3 positions several inches distant from each plant.

All of the steps in the planting process were done in much the same way as a planting machine might do them. The planting machine, as proposed and envisioned, will be fed by a small trailer with containerized cartridges of tubelings in a prearranged sequence depending on terrain and landscape design requirements. The operator will drill the planting hole with a side-mounted auger and then actuate the planting-basin scalper arm. The scalper will form a competition-free planting basin several feet in diameter. After the auger bit is removed from the planting hole, the tubeling will be dropped in and securely set in place by the squeezing action of a 3-bladed circularly arranged device inserted around the tubeling. It has been estimated that such a machine using this tubeling system might plant from one to several shrubs per minute under good planting conditions.

PLANTING SYSTEM 2

Plastic-Lined Condensation Traps

Another innovation to dry-land planting is the use of plastic-lined planting basins. The intent of these basins is not to catch precipitation but to condense subsoil moisture. This system has been found effective with standard plantings as well as with tubelings. Plastic aprons of various shapes and colors have long been used in landscape planting to eliminate weed competition, to facilitate close cultivating and mowing, to improve appearance, and even to repel insects (1). However, these uses have not primarily been intended to condense water vapor for plant use.

The principle used to pull up deep soil moisture is an old one—the "big flat rock" effect, the same phenomenon used in desert survival to obtain emergency drinking water. A vigorous shrub is planted in a specially designed basin, approximately 15 sq ft in area. Severe pruning is required. The basin is then lined with plastic and sealed by heeling-in around the edge. Plant foliage is brought up through a hole in the plastic (Fig. 4). The plastic liner thus reduces soil moisture evaporation in the vicinity of the planting (2). It collects saturated soil vapor carried above the surface where it condenses on the underside of the plastic liner. The condensate trickles down the taut plastic toward the plant and irrigates it (Fig. 5).

Initial field tests in late spring of 1968 were made on the side of an Interstate ramp at Huntley, Montana, a dry windy area, receiving 11½ in. of annual precipitation. Black and transparent plastic liners were compared. Several important findings regarding basin design were learned from this crude beginning. Planting basins placed on a slope will fill with sediment from thunderstorms, necessitating cleaning if provision is not made to automatically flush the sediment from the basin. This can be accomplished by

Figure 4. Clear plastic-lined basin is placed around a planting mound above the sediment accumulation zone on the basin floor; trough water through the lower edge of the basin rim allows precipitation to flush out accumulated sediment.

Figure 5. Accumulating condensate on under side of plastic liner trickles down toward the plant in basin floor, thus irrigating it.

providing a low outlet on the downhill rim (Fig. 4). In this way, if precipitation is heavy enough to wash sediment into the basin, it will be sufficient to move much of it out. Sediment accumulation may kill many species of plants. Planting on a raised mound above the floor of the basin reduced this problem.

To prevent premature dropping of condensate at other than the desired location and to keep the plastic liner stretched taut above the sides and floor of the basin, rock weights are placed on the plastic liner above the low points in the basin floor close to the plants (Fig. 6). Small slits are located beneath the rocks to drain entrapped precipitation. Weights are necessary also to help prevent flapping of the liner by the wind. The flapping action loosens the airtight seal around the basin rim and may cause the liner to tear.

The clear liner demonstrates well how rapidly condensate appears; often droplets form on the plastic before the basin construction job is completed. Clear plastic material lasts only one season before disintegrating, whereas the black shows no sign of weathering and is expected to last several seasons (3).

Recorded daytime temperatures measured in late July reached 118 F under clear liners but only 102 F under black (Table 1). Comparable nighttime temperatures were 47 and 46 F respectively. Direct comparisons of condensate collected from clear and black liners of adjacent similar-sized basins were variable but demonstrated the clear liner to be more effective than the black. This was not a measure of total condensation within the basin area (4) but merely that condensate collected from the underside of the plastic liner.

The quantity of condensate produced in a stated period of time is variable and depends on proximity and amount of soil moisture reserves, soil texture and color, size of the basin, color of plastic, temperature differentials, leaks in the plastic seal, and distance to bedrock (5). An average of 343 milliliters of condensate per day were collected from a clear liner during a 6-day interval in late summer. This accumulation of more than ½ gal seems more than ample to keep soil damp when soil moisture evaporation is controlled.

Responses caused by plastic color proved contrary to some expectations but substantiated previous work (4, 6), all of which added to the excitement of the study.

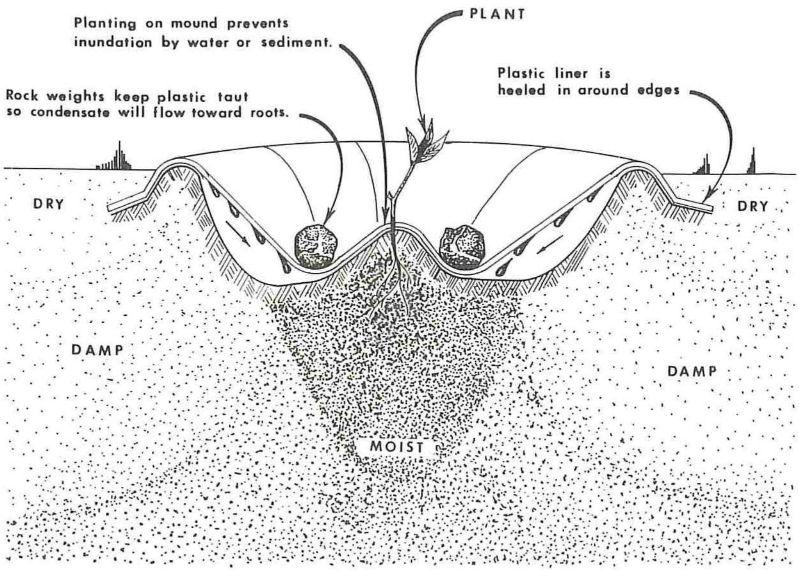

Figure 6. Cross-sectional view shows how plastic-lined planting basin conserves moisture.

TABLE 1

TEMPERATURE AND MOISTURE DATA FROM CONDENSATION TRAPS AT LOGAN, MONTANA

Outside Basin Temperature (F)		Date of Reading	Inside Basin Temperature (F)[a]		Time Period[b] (hr)	Plastic Color	Condensate Collected (ml)
Min	Max		Min	Max			
57	88	7-25-69	—	—	$21\frac{1}{2}$	Clear	73
		7-25-69	—	—	$21\frac{1}{2}$	Black	20
51	85	7-26-69	50	108	24	Clear	63
		7-26-69	52	103	24	Black	16
45	92	7-27-69	—	—	—	—	—
62	90	7-28-69	—	—	—	—	—
56	95	7-29-69	48	120	72	Clear	403
		7-29-69	50	110	72	Black	144
55	89	7-30-69	47	118	24	Clear	88
		7-30-69	46	102	24	Black	16
56	89	8-1-69	49	119	44	Clear	181
		8-1-69	51	113	44	Black	84
42	100	8-15-69	44	134	7	Clear	1,109
		8-15-69	41	122	7	Black	319
44	96	8-22-69	34	131	7	Clear	2,011
		8-22-69	38	114	7	Black	1,016
37	101	8-30-69	42	128	8	Clear	2,142
		8-30-69	32	126	8	Black	1,568
31	92	9-5-69	24	122	6	Clear	2,062
		9-5-69	22	110	6	Black	1,242

Note: Mean annual temperature, 46.5 F; mean annual precipitation, 10.3 in.; elevation, 4,035 ft.
[a]Temperatures recorded on basin bottom in shade.
[b]From July 25 through August 1, amounts are in hours; from August 15 through September 5, amounts are in days.

Admittedly, a tremendous amount of effort lies ahead before new approaches to roadside dry-land planting can become operational. Surely there are great potential savings to be had if a system can be found to mechanize the total planting process from nursery to roadside and to increase the survival rate of dry-land planting by perfecting these suggested techniques.

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Practices for Erosion Control on Roadside Areas in Georgia

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Several studies of erosion and establishment of vegetative cover on roadside areas in Georgia indicate that 5-year average sediment yields from bare roadside areas ranged from 78 to 234 tons/acre/year. Yearly sediment yields ranged from 25 to 455 tons/acre. After the establishment of a full vegetative cover and lining of ditches, these high sediment yields averaged less than 5 tons/acre/year for 3 years. Yearly sediment yields ranged from 0.12 to 11.5 tons/acre. Protection afforded by 2 tons/acre of straw as adequate for soil stabilization until plants could develop into a permanent cover. Forty-one plant species were tested at Cartersville and in the expanded program for adaptability in supplying protective cover on roadside areas. Eight of these species proved successful in the northern half of Georgia, and 8 species were also successful in the coastal plains. The best stands of Bahia grass were obtained when seeded alone and when seeded in March and June rather than in September. Stands were more difficult to obtain on sandy soils than on clay soils. Seeding rates above 40 lb/acre did not improve stands unless competition was removed. Maintenance fertilizer treatments at Cartersville showed that periodic applications adjusted to the plant needs were economical. Excessive rates of nitrogen and annual treatments increased material and labor costs and caused excessive plant residues on some areas. These residues tended to smother and thin the desirable plants.

•HEAVY SEDIMENT yields occur from steep, bare roadside areas in Georgia under high-intensity rainfall. Spew-frost action from cycles of freeze and thaw increases the erodibility of these exposed areas. In many instances this sediment is transported into lakes, reducing storage capacity and fish production and impairing recreational and other beneficial uses.

In 1956 studies were begun at Cartersville to determine sediment yields and factors causing erosion on bare banks. Simultaneously, studies were made of adaptation and effectiveness of plant species in controlling erosion. Species were planted alone and in combination to observe the compatibility of fast-growing, temporary plants with more permanent slow-growing varieties. Adequate and complete fertilizer and lime were worked into the soil, where possible, as the soil was prepared for seeding.

After planting, the treated areas were mulched with 2 and 4 tons/acre of straw or with commercial mulch materials that included woven fabrics, plastic sheets, wood fiber, and sprayed-on liquids. Generally, 2 tons/acre of straw, surface applied, were adequate for soil stabilization until plants could develop into a permanent cover (1, 2).

The vegetative studies were conducted initially within a 20-mile radius of Cartersville, in the limestone valleys and the middle and upper Piedmont soil provinces. The Cartersville data were not representative of conditions statewide because of the diversity of soils, elevation, and climatic conditions. Therefore, in 1964, the work was expanded to include species testing and other studies for the entire state at representative sites. Fall and spring plantings of various species were made in the mountains of

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TABLE 1

AVERAGE ANNUAL RAINFALL, RUNOFF, AND SEDIMENT YIELD FROM BARE ROADBANKS AT CARTERSVILLE FROM 1958 TO 1962

Plot	Plot Description[a]				Total Rainfall (in.)	Runoff (in.)	Sediment Yield (tons/acre)
	Exposure	Runoff Area (acre)	Erodible Area (acre)	Slope			
1	Northern	0.16	0.11	1.4:1	50.13	4.78	233.7
2	Southern	0.27	0.27	1.25:1	50.13	6.63	120.3
3	Northern	0.21	0.14	2.5:1	45.40	10.20	192.1
4	Southern	0.30	0.20	3.3:1	45.40	5.90	77.5
5	Northern	0.16	0.12	1:1	45.40	5.63	200.0
6	Southern	0.23	0.15	1.1:1	45.40	4.71	135.0

[a]All plots are on Cecil subsoil.

north Georgia, in the lower Piedmont at Griffin and Thomaston, in the upper coastal plains at Tifton, and on sandy and sandy clay soils of the lower coastal plains at Jesup. Other related studies that were conducted included runoff and sediment yields under bare and vegetative conditions, seeding mixtures of Bahia grass, and fertilizer applications for maintenance of roadside cover. Elevation of individual planting sites ranged from 4,000 ft at Brasstown Bald Mountain to 400 ft at Jesup. The other sites ranged from 900 to 700 ft in elevation.

RUNOFF AND SEDIMENT YIELDS AT CARTERSVILLE

Three pairs of runoff plots, with slopes of approximately 3 to 1, 2 to 1, and 1 to 1, were established in 1957. Members of the paired plots were located on opposite sides of the road to each other on a northern and a southern exposure. Runoff and sediment yields were measured with an N2 Coshocton sampler under bare conditions for a 5-year period. The 5-year average sediment yields ranged from 78 to 234 tons/acre/year (Table 1). Yearly sediment yields ranged from 25 to 455 tons/acre.

In 1963 a pair of plots (plots 1 and 2) was retained in a bare condition for control. Both plots had similar bank slopes and ditch gradients. Two pairs of plots (plots 3 and 4, and plots 5 and 6) were vegetated with plant species proven successful in the previous vegetative studies. Ditches to all plots were lined to prevent scouring to the ditch section, and road shoulders were fully protected.

Runoff and sediment yields during 1965 to 1967 of plot 1, which faced in a northern direction, were greater than yields of plot 2, which faced in a southern direction (Tables 1 and 2). Frost action was more severe on plot 1 than on plot 2 because of higher moisture content. Plots 3 to 6 inclusive were vegetated with different plant materials that

TABLE 2

AVERAGE ANNUAL RAINFALL, RUNOFF, AND EROSION FROM ROADBANKS WITH NO COVER AND WITH VEGETATION FROM 1965 TO 1967

Plot	Plot Description[a]					Total Rainfall (in.)	Runoff (in.)	Sediment Yield (tons/acre)
	Exposure	Runoff Area (acre)	Erodible Area (acre)	Slope	Cover			
1	Northern	0.16	0.083	1.4:1	None	52.95	11.55	150.82
2	Southern	0.27	0.173	1.25:1	None	52.95	11.09	123.83
3	Northern	0.21	0.048	2.5:1	Crown vetch and Abruzzi rye	53.29	8.28	4.43
4	Southern	0.30	0.023	3.3:1	Sericea lespedeza and love grass	53.29	4.31	1.18
5	Northern	0.18	0.022	1:1	Kentucky fescue	53.29	4.57	2.69
6	Southern	0.23	0.032	1.1:1	Pensacola Bahia grass and Bermuda grass	53.29	5.56	2.25

[a]All plots are on Cecil subsoil.

TABLE 3

COVER RATINGS MADE IN JUNE 1967 FOR FALL-PLANTED SPECIES AT VARIOUS LOCATIONS IN GEORGIA

Treatment	Seeded Species	Ratings (percent) by Location				
		Brasstown Bald Mountain[a]	Commerce[b]	Thomaston[c]	Griffin[c]	Jesup[d]
1	Chemong crown vetch	100	100	84	97	3
2	Penngift crown vetch	100	100	77	80	8
3	Emerald crown vetch	100	100	72	99	5
4	Fescue	0	25	37	40	5
	Penngift crown vetch	100	75	55	42	25
5	Fescue	0	75	87	93	38
	Crimson clover	0	25	10	4	45
6	English ivy	0	—	0	—	—
	Crown vetch spread in	100	—	75	—	—
7	Fescue	0	100	70	96	47
8	Honeysuckle	0	50	66	15	10
9	Day lilies	15	30	27	15	20
10	Vinca minor	0	0	0	0	0
	Crown vetch spread in	100	37	63	12	—
11	Sericea lespedeza	18	100	43	65	48
12	Monkey grass	—	15	—	9	0

[a]Mountain soil; planted September 1964.
[b]Upper Piedmont, Cecil clay; planted August 1965.
[c]Lower Piedmont, Cecil clay; planted October 1964 at Thomaston and September 1965 at Griffin.
[d]Lower coastal plain, sandy soil; planted October 1965.

developed to an effective cover. All plant materials, when fully developed, were almost equally effective in preventing soil losses.

LOCATION, MATERIALS, AND METHODS FOR FALL-PLANTED SPECIES

Beginning in September 1964, 11 fall-planted species or varieties, or mixtures of species, were established in 12 treatments at various locations (Table 3). Plantings were made in mid-September 1964 on Brasstown Bald Mountain. In early October, plantings were made on Cecil clay soils of the lower Piedmont at Thomaston. In late August 1965, plantings of fall species were made on clay soil at the northern edge of the Piedmont near Commerce. Other plantings were made on clay soil in mid-September 1965 at Griffin. The final planting of the fall series was made October 1965 on sandy soil of the lower coastal plains at Jesup.

The fall-planted species—English ivy (Hedera helix), honeysuckle (Lonicera varia), day lilies (Hemerocallis), vinca (Vinca minor), and monkey grass (Liriope muscarei)—were propagated vegetatively. Sericea lespedeza (Lespedeza cuneata) was planted by mulching plot areas with mature sericea plants filled with ripe seed. All other species were established with seed.

All plants were fertilized with 1,000 lb of complete fertilizer (10-10-10) and 2 tons/acre of lime. These materials were weighed for each plot and spread by hand. They were worked into the soil, usually by disking. The Brasstown Bald Mountain area was steep and bordered by forest; therefore, these plots were worked by hand.

RESULTS OBTAINED WITH FALL-PLANTED SPECIES

All varieties of crown vetch (Coronilla varia) provided excellent cover at Brasstown Bald Mountain, Commerce, Griffin, and Thomaston, but failed on the sandy soil at Jesup (Table 3). Crown vetch spread from planted plots to adjacent areas and gave good to perfect cover. Crown vetch required a special inoculation for success. Fescue (Festuca elatior) provided fair-to-good cover at Commerce, Thomaston, and Griffin, but failed at Brasstown Bald Mountain and at Jesup. English ivy, vinca, and monkey grass failed to survive. Day lily stands were generally good at all locations but required considerable care to provide adequate cover and roadside beauty.

TABLE 4

COVER RATINGS MADE IN JUNE 1967 FOR SPRING-PLANTED SPECIES AT VARIOUS LOCATIONS IN GEORGIA

Treatment	Seeded Species	Ratings (percent) by Location				
		Cleveland[a]	Thomaston[b]	Thomaston[c]	Jesup[d]	Jesup[e]
1	Midland Bermuda grass	25	83	65	90	–[f]
2	Midland Bermuda grass	35	55	20	88	–[f]
	White clover	65	45	0	0	–
3	Coastal Bermuda grass	70	100	30	100	49
4	Coastal Bermuda grass	60	65	40	100	35
	White clover	40	35	0	0	0
5	Bahia grass	85	100	80	90	85
	Common Bermuda grass	15	0	0	0	0
6	Bahia grass	75	100	45	90	84
	White clover	25	0	20	0	0
7	Sericea lespedeza	90	90	90	85	11
8	Sericea lespedeza	50	65	60	12	3
	Love grass	50	35	40	88	97
9	Virgata lespedeza	100	85	93	93	25
10	Virgata lespedeza	50	30	45	15	4
	Love grass	50	70	45	83	95
11	Brunswick grass	–	–	–	–	79

[a]Upper Piedmont, Cecil clay.
[b]Lower Piedmont, clay soil.
[c]Lower Piedmont, sandy soil.
[d]Lower coastal plain, sandy clay soil.
[e]Lower coastal plain, loamy sand.
[f]Brunswick grass replaced midland Bermuda grass on treatments 1 and 2 at Jesup.

Honeysuckle stands were satisfactory at Commerce, Thomaston, and Griffin, although growth and development were slow. More time was needed to develop full cover, especially at Griffin. Honeysuckle failed at Brasstown Bald Mountain and at Jesup. Apparently the extreme temperature and competition for moisture and sunlight were too great at these locations.

Best cover of sericea lespedeza, established from mulch seedings, was obtained at Commerce. Fair-to-good stands developed at Thomaston, Griffin, and Jesup, but stands failed rapidly at Jesup and on the Brasstown Bald Mountain sites.

MATERIALS AND METHODS FOR SPRING-PLANTED SPECIES

In the spring of 1965, 8 species or varieties, or mixtures of species, were planted at 3 locations (Table 4). These were planted near the fall plantings and on similar soils.

Plantings were made in late March 1965 on sandy clay soil of the lower coastal plains at Jesup. Plantings were also made in April at Thomaston and in May at Cleveland. Both of these plantings were made on clay soils of the lower and upper Piedmont respectively. In late March 1966, spring-planted species were repeated at Jesup. In early May 1966, spring-planted species were repeated at Thomaston. The second Thomaston planting was lost because of excessive rainfall.

Midland Bermuda grass (Cynodon dactylon) and coastal Bermuda grass (Cynodon dactylon) were planted vegetatively. Pensacola Bahia grass (Paspalum notatum), Brunswick grass (Paspalum), sericea lespedeza (Lespedeza cuneata), virgata lespedeza (Lespedeza virgata), love grass (Eragrostic curvula), and common Bermuda grass (Cynodon dactylon) were all propagated by seed.

RESULTS OBTAINED WITH SPRING-PLANTED SPECIES

Results of spring plantings are given in Table 4. Midland Bermuda grass survived on sandy clay soil at Jesup until full cover was developed, but by June 1967, all plants were dead. The residue provided approximately 90 percent cover. At the other 2 locations, Bermuda grass cover ranged from 20 to 83 percent. The overall average cover was approximately 50 percent at the 2 locations.

Coastal Bermuda grass survived better than midland Bermuda grass at Jesup and equally as well in north Georgia. Coastal Bermuda grass cover ranged from 30 to 100 percent among the locations. The overall average was approximately 75 percent.

Pensacola Bahia grass provided cover ranging from 45 to 100 percent. The average cover was 80 percent at all locations. From these studies it appears that Bahia grass may be safely planted at Thomaston and southward. Successful stands of Bahia grass have been observed north of Atlanta; however, the plants may be winter-killed when temperatures drop to zero.

Brunswick grass, a rhizomatous paspalum similar to Bahia grass, produced excellent cover on loamy sand at Jesup. Although this species was lightly seeded, it produced approximately 80 percent cover by the end of the second growing season.

Sericea lespedeza and virgata lespedeza established by spring seeding of scarified seed did well on clay soil at Thomaston and Cleveland. Seedings at Jesup were successful on sandy clay soil. Stands failed on loamy sand nearby. Good stands were obtained on the sandy areas, but most of the plants died during the first season. Stand and growth of sericea and virgata were better when seeded alone. Satisfactory stands of both species were obtained when seeded in mixtures with love grass, but stands and vigor were suppressed by excessive love grass growth. The stands of serica lespedeza and virgata lespedeza were adequate to dominate and provide full cover once the love grass vigor weakened.

Sericea lespedeza grew upright, whereas virgata lespedeza grew prostrate. Virgata lespedeza was smaller, appeared to be more leafy, and tended to recover faster after mowing than sericea lespedeza. Soils, fertilizer, seeding specifications, and climatic requirements for the 2 species appeared to be about the same.

Love grass was successful on both clay soils of north Georgia and on sandy soils of the coastal plains. In earlier tests at Cartersville, love grass died out in about 4 years. Lovegrass, at rates of 5 to 15 lb/acre, was valuable as a nurse crop for establishing crown vetch and the lespedezas. A seeding rate of 5 lb/acre of love grass seed appears to be adequate.

MATERIALS AND METHODS FOR BAHIA GRASS PLANTINGS

Pensacola Bahia grass planting studies were begun in 1964 near Tifton and Hinesville, with plantings in mid-March, June, and September. Different seeding dates were used to observe seasonal effects on emergence and growth of seedlings. On each of these dates, plantings were made on both sandy and clay soils. For each planting date and on each soil, Bahia grass was planted alone and in mixtures with common Bermuda grass, love grass, fescue, and Abruzzi rye (Secale cereale). All treatments were replicated 4 times at each location and on each planting date.

Fertilizer treatments for these studies consisted of 1,000 lb of complete fertilizer (10-10-10) and 2 tons of lime per acre. These materials were weighed for each plot, spread by hand, and disked into the soil. Seeds were weighed for each plot, broadcast by hand, and covered by cultipacking. All seedings were mulched with approximately 2 tons/acre of pine needles.

Bahia grass and rye were seeded at the rate of 40 lb/acre of seed. Common Bermuda grass, fescue, and love grass were seeded at the rate of 20 lb/acre, except at Hinesville, where different rates of love grass were used. Centipede grass (Eremochloa ophiuroides) was seeded at the rate of 5 lb/acre.

Near Hinesville, plantings of Argentine Bahia grass (Paspalum notatum), Pensacola Bahia grass, and centipede grass were made alone and with different rates of love grass. The seeding rates of love grass were 5, 10, 15, and 30 lb/acre.

RESULTS OF METHODS OF ESTABLISHING BAHIA GRASS

Results of Bahia grass seeding are shown in Figures 1 and 2. Stands of Bahia grass varied on both clay and sandy soils. This variation was caused mainly by lack of moisture and competition from companion crops and weeds. If moisture were available, good stands were obtained for all planting dates. Where moisture was low, poor stands usually resulted. The stand variation was greater on sandy soils than on clay soils.

Better stands and cover of Bahia grass developed from the March and June plantings than from the September seeding. Moisture apparently was more adequate at this season. Bahia grass planted in March grew larger, developed a better root system, and

was less likely to be pushed out of the soil by hard freezes the following winter. September- and even June-planted stands were sometimes thinned by winter freezes.

Superior stands and cover developed when Bahia grass was planted alone and when weed and grass competition was slight. Bahia grass stands and cover rated second when planted in mixtures with rye and fescue and third when planted with common Bermuda grass. Rye and fescue produced almost no growth from the March and June seeding and offered little competition to other grasses. Bermuda grass was not as competitive as love grass.

All seeding rates of love grass consistently reduced Bahia grass stands and cover on both clay and sandy soil. Love grass germinated more quickly and grew more rapidly than did the other companion species used. Severe competition for moisture and excessive shade from love grass almost completely eliminated Bahia grass stands.

MATERIALS AND METHODS FOR FERTILIZER MAINTENANCE STUDIES

In late summer of 1962 at Cartersville, 7 desirable species or mixtures of species were selected for fertilizer maintenance studies. Included were 2 perennial legumes: sericea lespedeza and crown vetch. The nonlegumes chosen were broom sedge (Andropogon varia), love grass, fescue, honeysuckle, and a mixture containing Pensacola Bahia grass and common Bermuda grass. Establishment procedures were standard and adequate for the respective species. Low rates of complete fertilizer, 400 lb/acre (15-15-15), were applied at seeding. Schedule and rate of applications of maintenance fertilizer treatments are given in Table 5.

Ground-cover ratings were made on the upper, middle, and lower one-third section of each plot and averaged to give a mean. No cover was rated 0, and complete cover

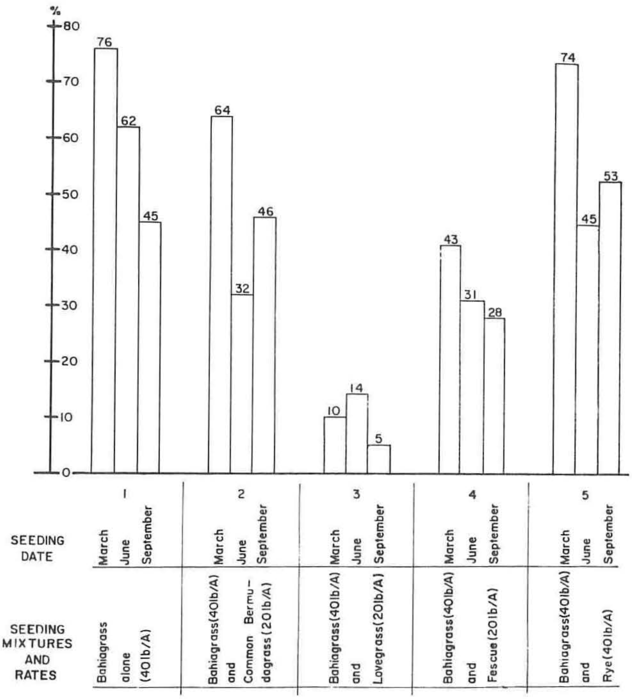

Figure 1. Average percentage cover of Bahia grass from 1964 to 1967 when seeded with companion crops in clay soil during mid-March, mid-June, and mid-September.

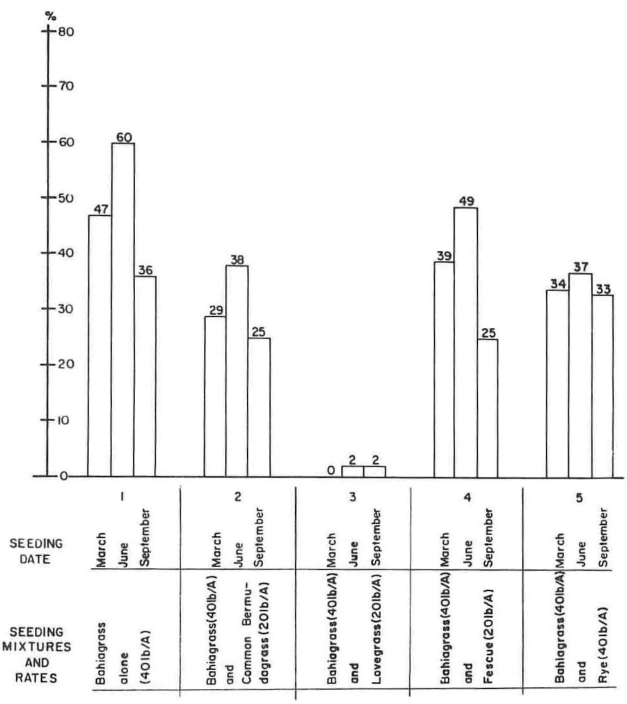

Figure 2. Average percentage cover of Bahia grass from 1964 to 1967 when seeded with companion crops in sandy soil during mid-March, mid-June, and mid-September.

was rated 10. Cover ratings were made in June just before harvest by 2 or more individuals and averaged to minimize bias.

Yields in lb/acre of dry materials were determined annually during periods of peak growth. Time of yield measurement varied with species. A swath was clipped through each test plot and green weights determined. Green weights were reduced to dry weights and averaged to provide a mean yield per acre for each species and for each individual treatment.

TABLE 5

SCHEDULE AND RATE OF APPLICATIONS OF MAINTENANCE FERTILIZER TREATMENTS

Treatment	Fertilizer for Legumes (lb/acre)			Fertilizer for Nonlegumes (lb/acre)			Frequency Application
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	
1	0	30	30	30	60	30	As needed[a]
2	0	60	60	60	60	60	As needed
3	0	120	120	120	120	120	As needed
4	0	30	30	30	60	30	Yearly
5	0	60	60	30	60	60	Yearly
6	0	120	60	60	60	60	Yearly
7	0	60	120	60	60	120	Yearly
8	0	0	0	0	0	0	Check

[a]Fertilizer was applied in 1964 and 1967.

RESULTS OF THE FERTILIZER MAINTENANCE STUDIES

Plant covers resulting from different fertilizer treatments are shown in Figure 3. Results of analysis of the data for the entire 5 years show that mean percentage surface cover was significantly higher for love grass and for the Bermuda-Bahia mixture than for all other species. Mean cover was significantly lower for broom sedge and honeysuckle than for all other species.

Year effect on mean percentage cover was quite marked. Cover increased with each successive year but, on the basis of these tests, it was well established by the third

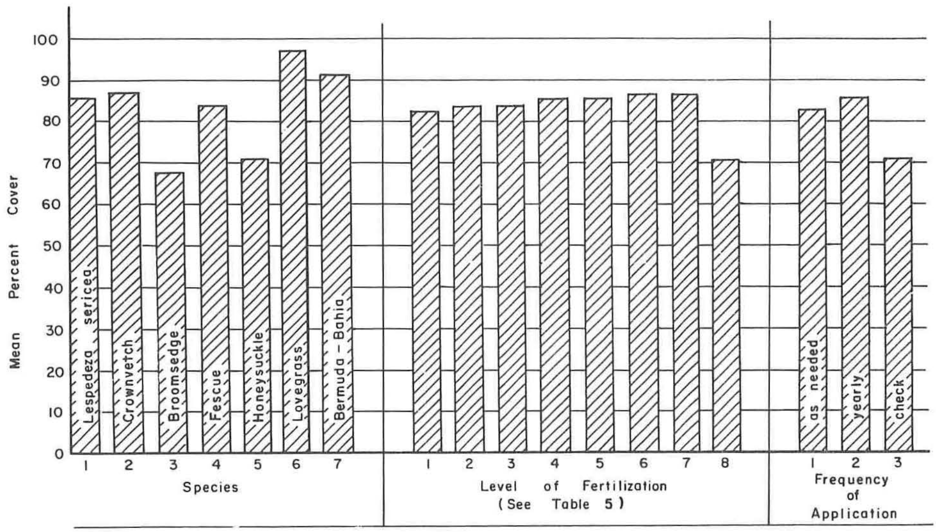

Figure 3. Mean percentage cover versus fertilizer treatment.

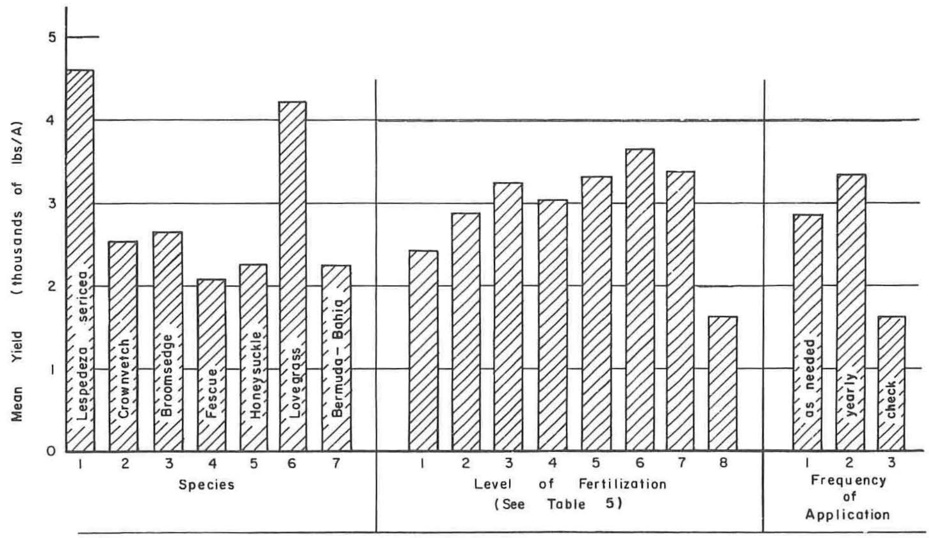

Figure 4. Mean yield versus fertilizer treatment.

year. Fertilizer treatments, as needed, provided cover almost as good as that provided by yearly fertilizer treatments and were more economical.

On the fifth year there was no significant difference in the mean percentage surface cover produced by the 7 plant species and for the various fertilizer treatments. Cover was well established for all treatments with mean average ranging between 95 and 100 percent.

Yields resulting from different fertilizer treatments are shown in Figure 4. Mean yields of sericea lespedeza and love grass over the 5-year period were significantly greater than those for all other species. Stems of these species were resistant to decay; therefore, some residue from the previous year was included in the yield measurements. On the fifth year, only sericea lespedeza gave a significantly higher yield than the other species. Yearly effect on mean yield was not well defined. Yearly variations in yield possibly are explained by yearly variations in weather and related growing conditions.

Over the 5-year period, yearly fertilizer applications resulted in mean yields significantly greater than those of the other treatments. In year 5 there was no significant difference in mean yield for the various levels of fertilization. Check-plot yields were significantly lower for the 5-year period for all species.

SUMMARY AND CONCLUSIONS

In this report, results from several studies concerned with erosion and the establishment of vegetative cover on roadside areas in Georgia were analyzed and brought together. The practices found suitable in these studies should be applicable to the respective soil provinces in states where climatic conditions are similar to those in Georgia.

The 5-year average sediment yield from bare roadside areas in Georgia ranged from 78 to 234 tons/acre/year. Yearly sediment yields ranged from 25 to 455 tons/acre. After a fully vegetative cover was established and ditches were lined, these high sediment yields averaged less than 5 tons/acre/year for 3 years. Yearly sediment yields ranged from 0.12 to 11.5 tons/acre. Two tons of straw/acre afforded adequate protection until plants could develop into a permanent cover.

Forty-one plant species were tested for adaptability in supplying a protective cover on roadside areas. The following plants proved successful in the northern half of Georgia: Wilmington Bahia grass, grew successfully at Cartersville from 1957 to 1964 and withstood a temperature of 8.5 deg below zero while Pensacola and Argentine Bahia grasses were winter-killed; fescue; midland Bermuda grass; day lilies, useful for special areas where color was desired; native honeysuckle, on the Piedmont; crown vetch; sericea lespedeza; and virgata lespedeza. Light seedings of common Bermuda grass and love grass were useful as nurse crops for spring seedings of crown vetch, virgata lespedeza, and sericea lespedeza. Light seedings of rye, ryegrass, or fescue were excellent nurse crops for fall-seeded crown vetch.

The following plants proved successful in the coastal plains: Pensacola Bahia grass; Argentine Bahia grass, in the lower coastal plains; coastal Bermuda grass; love grass; Brunswick grass, in the lower coastal plains; common Bermuda grass; Wilmington Bahia grass, adaptable since grown successfully at Cartersville from 1957 to 1964; and day lilies, used in areas where ornamentals and color were desired, and successfully planted in the fall, winter, and spring.

Studies concerned with the establishment of Bahia grass led to a number of conclusions:

1. Stand development was more difficult to obtain on sandy soil than on clay soil;
2. Stands developed from March and June plantings were more successful than those from September seedings;
3. Best stand and cover developed when planted alone, with the next best stand and cover obtained from mixture with rye on clay soil and with fescue on sandy soil; and
4. Seeding rates of more than 40 lb/acre did not improve stands unless competition was removed.

Several important conclusions were drawn from fertilizer maintenance studies:

1. Mean cover ratings of plots receiving annual fertilizer application only slightly exceeded those from as-needed applications, which proved to be adequate and were more economical;
2. Of the 7 species tested, the highest cover ratings were obtained for love grass and for the Bermuda-Bahia grass mixture, and the poorest ratings were obtained for broom sedge and honeysuckle;
3. Although plants in the check plot provided lower percentage cover than where fertilizer was applied, in most cases, the cover was fair to good; and
4. Sericea lespedeza and love grass gave higher yields than the other species tested, and the check-plot yields were significantly lower than those of the fertilizer plots.

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Weed Control on Oklahoma Highways

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Roadside weed control research in Oklahoma is concerned both with selective and nonselective herbicides for the control of undesirable grasses and broad-leaved weeds. The evaluation of herbicides for the most effective and economical means of weed control on the highway system is the objective of this research program. These research results, even though involved with a common purpose, are presented as 3 separate studies for clarity and convenience. The post-emergence herbicides such as AMA (ammonium methanearsonate), CMA (calcium acid methyl arsonate), DSMA (disodium methanearsonate), and MSMA (monosodium acid methanearsonate), each with one retreatment 7 to 20 days after the initial application, are equally effective in the control of sandburs. Based on the cost per acre, DSMA is the least expensive. The pre-emergence application of Atrazine is the most effective herbicide for the control of both broad-leaved weeds and annual grasses commonly found on Oklahoma highways. For only broad-leaved weeds the herbicides 2,4-D amine, 2,4,5-T amine, and Dicamba (Banvel-D) are recommended; based on cost per acre, 2,4-D generally is the least expensive. The most effective herbicides for the control of alfalfa (Medicago sativa) and sweet clover (Melilotus officinalis) are 2,4-D amine, 2,4,5-T amine, and Dicamba (Banvel-D); 2,4-D generally is the least expensive. The organic arsonate herbicides, DSMA and MSMA, are the most effective materials evaluated for the selective control of Johnson grass. Based on cost per acre, DSMA is the least expensive. The herbicides recommended for the suppression of all plant growth, especially Bermuda grass on shoulders, under guardrails, and around signposts, are Bromacil, Borocil, TCA Inhibited, Borea T-10, and a combination of TCA and Bromacil. Based on the cost per foot-mile, TCA Inhibited is the least expensive.

• THE HIGHWAY PROGRAM in Oklahoma requires modern, efficient methods for establishing and maintaining desirable vegetation on the rights-of-way if it is to provide maximum services with a minimum of expenditure. More than 15,000 miles of state and federal highways and roads are presently maintained by the Oklahoma Department of Highways. Herbicides are being used successfully in most areas to minimize hand labor in the maintenance programs around guardrails and signposts, to reduce the frequency of mowing, and to improve the effectiveness and reduce the costs of weed control on grass-covered areas.

The roadside weed control research in Oklahoma is concerned both with selective and nonselective herbicides for the control of undesirable grasses and broad-leaved weeds. The investigations had the common objective of weed control and were divided into 3 parts as follows: broad-leaved weed and annual grass control, Johnson grass control, and soil sterilization.

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BROAD-LEAVED WEED AND ANNUAL GRASS CONTROL

Two methods generally available for the control of weeds in grass-covered areas are mechanical or chemical. Both methods have been used with success. The principal objective here is to use the most satisfactory and economical method for weed control on the various highway areas.

Successful weed control by mechanical methods generally is restricted to those weeds that perpetuate themselves by seed. Careful timing of the mowing operations to coincide with the flowering periods of the many weeds and repeated removal of the flowers to prevent seed production should ultimately eliminate the weeds from an area. Weed control by mechanical methods generally is less effective and more expensive than control by chemical means. Of even greater importance is the loss of life each year in mowing accidents.

Sandbur Control

Weeds that are to be found on highway rights-of-way generally detract from the overall beauty of the area. They also may create a lasting, unpleasant memory of the state if a person suffers physical pain that some species can inflict on contact. One such plant in Oklahoma is the sandbur (Cenchrus pauciflorus Benth.) that produces numerous spiny burs and virtually renders an area unusable by man or animal.

In 1966 the first of 5 experiments was initiated to evaluate pre- and post-emergence herbicides and their combinations for the selective control of sandburs in Bermuda grass turf. The soils at all locations are sandy, sparsely covered with Bermuda grass, and heavily infested with sandbur. None of the areas had received maintenance applications of fertilizer since the Bermuda grass was established. Detailed descriptions of these experiments are reported by Roach (1).

In the first investigation located in north central Oklahoma near Stillwater on Okla-33, the pre-emergence herbicides were applied in 30 gal of water per acre and the post-emergence materials were applied in 40 gal/acre. The post-emergence herbicides were significantly more effective for sandbur control than the pre-emergence materials or a combination of the two (Table 1). The organic arsonates, AMA (ammonium methanearsonate) at 3.8 lb of active ingredient (ai)/acre, MSMA (monosodium acid methanearsonate) at 2.0 lb of ai/acre, and CMA (calcium acid methyl arsonate) at 3.7 lb of ai/acre, showed complete sandbur control.

TABLE 1

COMPARISON OF PRE-EMERGENCE AND POST-EMERGENCE HERBICIDES FOR CONTROL OF SANDBUR PLANTS IN BERMUDA GRASS TURF

Chemical	Rate (lb of ai/acre) by Date of Application				Mean Number of Live Plants per 10 Sq Ft	Percent Control
	3-30-66	5-25-66[a]	9-1-66	9-19-66		
Post-emergence						
AMA		3.8	3.8	3.8	0.0	100.0
MSMA		2.0	2.0	2.0	0.6	98.9
CMA		3.7	3.7	3.7	1.3	97.6
CMA and		3.7				
Betasan		4.0			22.6	57.6
Pre-emergence						
Zytron	15.0				36.0	33.3
Atrazine	3.2				45.3	16.1
Simazine	3.2				45.3	16.1
Betasan	20.0				45.6	15.6
Dacthal	10.0				68.0	-25.9[b]
Check					54.0	

Note: Chi-square significance at the 0.5 percent level.

[a]Because of unfavorable weather conditions, the plots did not receive the retreatment on the desired interval of 7 to 20 days after initial treatment. The post-emergence materials only were applied again on September 1, and retreated on September 19.

[b]No control was exhibited by Dacthal.

Only the post-emergence herbicides from the initial investigation were evaluated in subsequent studies along with 2 other post-emergence materials—another organic arsonate DSMA (disodium methanearsonate) at 2.5 lb of ai/acre and Monex {MSMA plus Diuron [3(3,4-dichlorophenyl)-1, 1 dimethylurea]} at 1.2 lb of ai/acre. In 1967 four experiments were initiated. In these studies all herbicides were applied in 40 gal of water per acre and retreated once 7 to 20 days after the initial application. All of the post-emergence herbicides used in 1967 were satisfactory in the control of sandburs in Bermuda grass turf (Table 2), with only slight differences indicated among materials.

TABLE 2

EFFECTS OF POST-EMERGENCE HERBICIDES ON CONTROL OF SANDBUR PLANTS IN BERMUDA GRASS TURF

Chemical	Rate (lb of ai/acre) by Date of Application		Mean Number of Live Plants per 10 Sq Ft	Percent Control
	6-15-67	7-10-67		
AMA	3.8	3.8	0.66	99.0
DSMA	2.5	2.5	0.66	99.0
MSMA	2.0	2.0	1.00	98.4
CMA	3.7	3.7	1.00	98.4
Monex	1.2	1.2	1.33	97.9
Check			61.33	

Note: Chi-square significance at the 0.5 percent level.

The cost per acre for the organic arsonates (based on wholesale prices for small quantities) per application to effectively control sandburs if applied twice at 7 to 20 day intervals is given in Table 3.

General Weed Control

Seven experiments were conducted in the evaluation of pre- and post-emergence herbicides (in addition to the five concerned with sandbur control) for the control of broad-leaved weeds and annual grasses. One study initiated in 1965 on US-270 was also concerned with the residual activity, if any, 2 years after application. The results of this investigation are given in Table 4; only shown are those materials that were applied as pre-emergence treatments and that produced in the year of application 80 percent or more control of broad-leaved weeds or annual grasses or both.

Atrazine at 3 lb of ai/acre provided about 92 percent control of all broad-leaved weeds and 96 percent control of the annual grasses when evaluated in mid-July 1965. One year later this herbicide exhibited a residual control of 55 percent of the broad-leaved weeds and 62 percent of the annual grasses when evaluated on May 23, 1966.

The cost per acre to apply 3 lb of active ingredient of Atrazine (using 3.75 lb of 80 percent wettable powder) based on wholesale prices for small quantities is $9.26. For only broad-leaved weed control, Picloram (Tordon), which contains 4 lb of ai/gallon, costs $7.75 to apply 0.5 lb of ai/acre.

TABLE 3

COST PER ACRE OF HERBICIDES RECOMMENDED FOR SANDBUR CONTROL IN BERMUDA GRASS TURF

Herbicide	Amount Active	Commercial Material per Application per Acre	Cost per Acre per Application
AMA	1.4 lb/gal	2.7 gal	$16.17
CMA	1.0 lb/gal	3.7 gal	12.40
DSMA	6.3 percent	4.0 lb	1.44
MSMA	4.0 lb/gal	3.0 qt	3.56

TABLE 4

EFFECT OF VARIOUS HERBICIDES AND THEIR RESIDUAL ACTIVITY ON CONTROL OF BROAD-LEAVED WEEDS AND ANNUAL GRASSES

Herbicide	Rate (lb of ai/acre)	Date Applied	Percent Control (8-10-67)	
			Weeds[a]	Grasses[b]
Atrazine	3.0	4-12-65	56	65
		4-6-66	61	77
		4-11-67	91	92
Picloram	0.5	5-17-65	73	30
		7-28-66	82	29
		7-17-67	90	28
Atrazine	1.5	4-12-65	64	48
		4-6-66	67	69
		4-11-67	84	87
Simazine	3.0	4-12-65	53	54
		4-6-66	59	58
		4-11-67	87	83

[a]Plants commonly found in early spring are henbit (Lamium amplexicaule), wooly plantain (Plantago purshii), and vetch (Vicia spp.). In midsummer they are perennial ragweed (Ambrosia psilostachya), haplopappus (Haplopappus ciliatus), lespedeza (Lespedeza japonica), buttonweed (Diodia teres), conyza (Conyza canadensis), and buffalo bur (Solanum rostratum).
[b]Grasses common to the area are annual bromegrasses (Bromus spp.), hairy crabgrass (Digitaria sanguinalis), and triple-awned grass (Aristida olingantha).

Legume Control

Two plants that are common on the roadsides and in the medians of numerous Oklahoma highways are alfalfa (Medicago sativa) and yellow sweet clover (Melilotus officinalis). These important forage and pasture legumes are becoming weed problems for the highway department and require frequent and costly mowing of the highway system.

In 1967 two investigations were initiated to evaluate several herbicides for the selective control of alfalfa and sweet clover. These experiments are described in detail by Bhrommalee (2). The materials found to be most effective of those evaluated for the control of alfalfa and sweet clover were 2,4-D, 2,4,5-T, Fenac, and Dicamba (Banvel-D). The costs of these herbicides are given in Table 5, based on wholesale prices for small quantities.

JOHNSON GRASS CONTROL

The abundance of Johnson grass (Sorghum halepense L.) seems to increase each year along Oklahoma highways. When allowed to grow, the plants may become so tall and dense as to restrict the drivers' view on curves, railroad crossings, and intersections. In addition to the driving hazards that are created by Johnson grass, the plants detract from the general beauty of the area and serve as a source of infestation of this noxious weed into adjacent cropland. A substantial portion of the mowing costs on Oklahoma highways is expended for the intended control of Johnson grass.

In August 1963 two of eleven experiments were initiated to evaluate several herbicides for the selective control of Johnson grass on the Oklahoma highway system. One study was on I-35 near Mulhall and the other on Okla-33 near Coyle, both in north central Oklahoma. These experiments and others are described in detail by Sinkler (3). The herbicides, Monobor-Chlorate-D, Dalapon, and DSMA, each in 100 gal of water were applied at a rate to wet the foliage in each experiment. The Dalapon and DSMA treatments were reapplied in October 1963. Dalapon and DSMA were completely soluble in water but Monobor-Chlorate-D was not. A surfactant was applied with DSMA in all cases. In one treatment the Johnson grass was mowed to a height of 6 in. so that it would be in a vegetative stage at the time of application, and in the other treatment the plants were in the seed-head stage when the herbicides were applied. The results of these 2 experiments are given in Table 6. Although the values are not exactly the same, the order and magnitude of control are similar.

The results of subsequent experiments for the selective control of Johnson grass indicated that many of the herbicides used, such as DSMA, MSMA, Dalapon, Monobor-Chlorate, and Bromacil—Monobor-Chlorate combination, produced significant control of Johnson grass but some severely damaged the desired Bermuda grass. It was concluded from these studies that the organic arsonate herbicides DSMA and MSMA are best suited for the selective control of Johnson grass on Oklahoma highways. A detailed description of these experiments is presented by Schneider (4). These studies indicate that the best results will be obtained when the Johnson grass plants are treated when 12 to 18 in. tall and actively growing, and when the sun is bright and

TABLE 5

COST PER ACRE OF EFFECTIVE HERBICIDES EVALUATED FOR SELECTIVE CONTROL OF ALFALFA AND SWEET CLOVER

Herbicide	Rate (lb of ai/acre)	Cost per Acre
Dicamba (Banvel-D)	0.75	$ 4.69
2,4-D	1.0	1.56
2,4,5-T	1.0	2.96
Fenac	7.5	41.50

TABLE 6

EFFECT IN 1964 OF THREE HERBICIDES APPLIED IN 1963 ON STAND OF JOHNSON GRASS IN MOWED AND UNMOWED PLOTS

Herbicide	Initial Rate (lb of ai)	Relative Density (percent)[a]	
		Mowed	Unmowed
Check	—	60	47
DSMA	1.9/100 gal	13	32
DSMA	3.2/100 gal	18	39
Dalapon	10/acre	10	29
Dalapon	15/acre	11	24
Monobor-Chlorate-D	643/acre	0	5
Monobor-Chlorate-D	1,089/acre	0	0

[a]Treatment differences significant at the 1 percent level of probability.

TABLE 7

PERCENTAGE CONTROL OF JOHNSON GRASS PRODUCED BY TWO RATES OF DSMA FOR ONE OR MORE YEARS AT NINE LOCATIONS

Location	Rate (lb of ai)	Percent Control					
		Mowed			Unmowed		
		1967	1966	1965	1967	1966	1965
Ada	2.5/acre	92			65		
	5.0/acre	98			94		
Alva	2.5/acre		70	78		82	86
	5.0/acre		93	87		62	85
Fort Gibson	2.5/acre	93	68	89	99	90	79
	5.0/acre	99	92	85	99	94	76
Mulhall	3/100 gal		55	56		16	63
	5/100 gal		52	78		36	73
Meeker	2.5/acre	95	97	93	88	98	77
	5.0/acre	90	99	91	90	98	83
Sand Springs	3/100 gal		49	54		13	55
	5/100 gal		41	44		56	59
Pawnee	2.5/acre		82	88		88	86
	5.0/acre		91	74		88	77
Perkins	3/100 gal		55	53		52	41
	5/100 gal		64	81		53	70
Texoma	2.5/acre	72	88		57	53	
	5.0/acre	93	93		89	81	

the temperature is 80 F or higher. The effect of DSMA plus 1 percent surfactant on the control of Johnson grass is given in Table 7.

The cost per acre for the organic arsonate herbicides (based on wholesale prices for small quantities) per application to effectively control Johnson grass on Oklahoma roadsides is given in Table 8. Two or three applications per year will be required for the most effective control.

SOIL STERILIZATION

Soil sterilization is commonly used in several state highway maintenance programs for more efficient and economical maintenance under guardrails, around signposts, and on shoulders. In these areas all plant growth is suppressed for the safety of the motoring public and the preservation of the highway through the protection of the asphaltic shoulders. The potential benefits of these chemicals are offset in some cases by the improper application of the materials or by the downslope movement from the place of application, killing all vegetation, thereby leaving the soil exposed to erosion and perhaps the ultimate loss of the highway at that point.

The plant species commonly found and oftentimes quite difficult to control on Oklahoma highways are common Bermuda grass (Cynodon dactylon) and Johnson grass (Sorghum halepense). These become troublesome on the highway shoulders particularly when the underground stems or shoots break through the asphaltic surface and open a channel for water penetration into the roadbed.

Nine experiments were conducted to evaluate various chemicals for the elimination of all vegetation, especially Bermuda grass on highway shoulders and around guardrails. The orderly removal or prevention of plant growth in these areas through the use of chemicals conceivably might reduce the time and labor involved in maintenance.

In 1964 one experiment was initiated on Okla-51 near Stillwater in north central Oklahoma to evaluate several chemicals for the control of Bermuda grass on the highway shoulders. The herbicides were applied with spray equipment in 12.1 gal

TABLE 8

COST PER ACRE OF HERBICIDES RECOMMENDED FOR JOHNSON GRASS CONTROL

Herbicide	Amount Active	Commercial Material per Application per Acre	Cost per Acre per Application
DSMA	6.3 percent	4.0 lb	$1.44
MSMA	4.0 lb/gal	3.0 qt	3.56

TABLE 9

EFFECT OF VARIOUS CHEMICALS APPLIED IN 1964
ON THE CONTROL OF BERMUDA GRASS

Herbicide	Rate (lb of ai/acre)	Percent Control in 1967	Herbicide	Rate (lb of ai/acre)	Percent Control in 1967
Bromacil	24	100	Borea T-10	250	91
Borocil	327	97	Borea T-10	500	89
Urox-32	300	96	Prometone	20	89
TCA and Fenac	100 and 8	96	Baron (in diesel)	120	88
Bromacil (in diesel)	12	95	Monobor-Chlorate	870	87
Prometone	40	95	Monuron	64	87
TCA	300	94	Bromacil and Knockdown	12	87
TCA and Bromacil	80 and 10	93	TCA and Fenac	150 and 8	86
Chlorea	870	93	Baron and Dalapon	68 and 17	85
Monuron	32	93	Monobor-Chlorate	1,740	82
Borocil	218	92	Baron	160	80
Chlorea	650	92	Ureabor and Knockdown	400	80
Ureabor	1,200	91	Monobor-Chlorate and Knockdown	870	80
Urox-32	150	91	Fenac	20	79
TCA and Bromacil	80 and 5	91	Bromacil	12	77
Baron and Dalapon	80 and 10	91	Fenac	30	73
			Untreated	—	66

of water per foot-mile, which equals 100 gal/acre, with the exception of Urox that was applied in diesel fuel at the same rate. One treatment of Bromacil, Baron, and Monuron was in diesel fuel also. The granular materials were applied with a horn seeder. Although the chemicals have not been fully evaluated, the most effective materials were Bromacil, Urox, Prometone, Ureabor, Chlorea, Borocil, the combination of TCA and Bromacil, and TCA alone. The results of this experiment are given in Table 9.

A similar experiment was initiated in March 1965 on Okla-99 near Wynona in north central Oklahoma to evaluate various chemicals for the control of Bermuda grass particularly on the shoulders. A second application of these materials at one-half the original rate was made on June 15, 1966. The results of these evaluations, although not complete, indicate that the most effective herbicides for the control of Bermuda grass in this area are TCA at 150 lb, Urox at 300 lb, and Bromacil at 24 lb of ai/acre. The downslope movement of Urox at this rate was considered excessive and would be undesirable on roadside slopes.

Another experiment was initiated in March 1965 on Okla-92 near Chickasha in central Oklahoma. It is an exact duplicate of the study at Wynona. Although the complete evaluation of these chemicals have not been made, the results indicate that the most effective materials for the suppression of Bermuda grass are Bromacil at the rate of

TABLE 10

COST PER FOOT-MILE OF HERBICIDES EFFECTIVE IN
CONTROL OF BERMUDA GRASS

Herbicide	Percent Active	Commercial Material per Application per Foot-Mile (lb)	Cost per Foot-Mile
Borocil	98	40.4	$16.97
Bromacil	50 Hyvar X-WS	5.8	20.01
	80 Hyvar X	3.6	18.54
TCA Inhibited	91	20.0	7.10
TCA and Bromacil	(see above)	10.6 and 2.4 at 50 percent	12.04
		10.6 and 1.5 at 80 percent	11.49
Borea T-10	58	104.3	26.06

24 lb of ai/acre, TCA at 150 lb, Urox at 300 lb, Monobor-Chlorate at 1,740 lb, Borocil at 327 lb, Borea T-10 at 500 lb, and a combination of 80 lb of TCA and 5 lb of Bromacil. These data are in general agreement with those obtained earlier by Sinkler (3).

Based on the results from all experiments designed to evaluate various chemicals for the suppression of plant growth, especially Bermuda grass on shoulders and under guardrails of the Oklahoma highway system, the most effective materials are Bromacil at 24 lb of ai/acre, Borocil at 327 lb, TCA at 150 lb, Borea T-10 at 500 lb, and a combination of 80 lb of TCA and 10 lb of Bromacil. The cost of these chemicals per foot-mile for the most effective suppression of Bermuda grass on highway shoulders is given in Table 10. These chemicals and rates, alone and in combination, possibly will change with further evaluation.

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In order that the information in this paper may be more useful, it was sometimes necessary to use trade names of products rather than complicated chemical identifications. As a result, it is unavoidable in some cases that similar products that are on the market under other trade names may not be cited. No endorsement of named products is intended, nor is criticism implied of similar products that are not mentioned.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Oklahoma Department of Highways or the Federal Highway Administration.

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Effects of Interstate Right-of-Way Mowing on Wildlife, Snow Buildup, and Motorist Opinion in North Dakota: A Preliminary Report

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Use of Interstate rights-of-way by birds and mammals warrants wildlife management attention. Twenty-three miles of I-94 right-of-way in North Dakota contained 264 game bird nests including 249 duck nests. Nesting success was 58.8 percent in 1968 and 65.4 percent in 1969. Ducks responded quickly to cessation of mowing when alternate miles of the right-of-way and half the interchange triangles were left unmowed. Seventy-four percent of the ducks chose unmowed nesting sites. Thirty-four percent of the right-of-way waterfowl nests were not hatched by July 4 mowing. Unmowed right-of-way vegetation did not cause snow buildup on the driving surface. The majority (82 percent) of 182 motorists interviewed had not noticed the mowed-unmowed conditions of the right-of-way. Most preferred the mowed condition when asked about the treatments. Numbers and species of wildlife killed by cars in the study area fluctuated with population changes. No increase was noted during the year of alternate mowed-unmowed miles. Recommendations include delayed or curtailed mowing on Interstate right-of-way in waterfowl-producing regions. Such practices will increase nesting success and reduce highway maintenance costs.

•NO GREATER DANGER threatens America's wildlife than loss of habitat. The wildlife crisis arising in the face of intensified land use and burgeoning human populations is already manifest in reduced wildlife populations and even extinction of species.

Wildlife agencies have developed land acquisition programs at both state and federal levels to partially offset this loss. Such programs are expensive and small in size. However, at no additional land cost, our system of highway rights-of-way, if properly managed, could significantly increase wildlife populations. In North Dakota alone approximately 1 million acres of rights-of-way are potential wildlife habitat. Most of this real estate is publicly owned. Unfortunately, right-of-way maintenance often destroys this habitat.

About $3.5 million is spent nationally each year to control vegetation on Interstate rights-of-way (17). Highway maintenance engineers have recommended less mowing on Interstate highways to curtail costs (1). North Dakota reduced Interstate mowing in 1967 (18), and South Dakota recently followed suit (19). Nebraska also follows a schedule of limited mowing (20).

Purposes of this study were to survey the wildlife on a portion of North Dakota's I-94 and to evaluate the effects of mowing and nonmowing on wildlife, snow buildup,

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wildlife car-kills, and motorists' opinions. From this study we have offered maintenance recommendations that will enhance wildlife habitat and be consistent with maintenance problems.

This paper deals with work completed in 1968 and 1969. Continued work is scheduled for 1970 and possibly for 3 more years. A similar study is currently under way on the Northern Pacific railroad right-of-way in North Dakota.

I-94 IN PRAIRIE POTHOLE COUNTRY

Twenty-three miles of right-of-way, on both sides of I-94 from Oswego to one-half mile east of Crystal Springs plus 24 triangles at 6 interchanges are within the study area. The grassy right-of-way varies from 40 to 460 ft in width. Interchange triangles vary from 0.6 acres to 1 acre each. Total area of the study strip and triangles is about 630 acres.

The terrain is rolling with many wetlands. Vegetation of the right-of-way forms a uniform community of smooth brome (Bromus inermis) with scattered stands of Kentucky bluegrass (Poa pratensis), crested wheatgrass (Agropyron cristatum), slender wheatgrass (Agropyron trachycaulum), and volunteer yellow wheat clover (Melilotus officinalis) and alfalfa (Medicago sativa). Shrubs and other woody vegetation are absent.

The right-of-way is frequented by mallards (Anas platyrhynchos), blue-winged teal (Anas discors), gadwalls (Anas strepera), shovelers (Spatula clypeata), pintails (Anas acuta), lesser scaup (Aythya affinis), gray partridge (Perdix perdix), sharp-tailed grouse (Pedioecetes phasianellus), ring-necked pheasants (Phasianus colchicus), upland plovers (Bartrami a longicauda), red fox (Vulpes vulpes), raccoons (Procyon lotor), badgers (Taxidea taxus), striped skunks (Mephitis mephitis), Richardson ground squirrels (Citellus richardsoni), white-tailed deer (Odecoileus virginianus), long-tailed weasels (Mustela frenata), and a variety of gulls, hawks, shorebirds, mice, voles, songbirds, and other animals.

Right-of-way maintenance in the study area formerly involved complete mowing by either the adjacent landowners on hay bids or the highway department. In recent years only the inslope and interchange triangles were mowed if no hay bids were received. The study area was completely mowed in 1967. In 1968 and 1969 alternate miles were mowed according to the design of this study. Hay revenue was \$534.50 in 1967, \$173.75 in 1968, and \$255.00 in 1969. It is doubtful that hay revenue results in net income to the highway department because of administration costs (18).

Most rights-of-way literature (5, 6, 7) has been concerned with transmission line rights-of-way through eastern deciduous forests. Wildlife studies on Interstate highway rights-of-way is sparse. Highway Research Board abstracts show no Interstate right-of-way wildlife studies (21). South Dakota, Nebraska, Minnesota, Kansas, and Iowa report no Interstate right-of-way wildlife projects (20, 22, 23, 24, 25).

The importance of rights-of-way for game bird nesting habitat has been documented. In Illinois Joselyn, Warnock, and Etter found higher pheasant nest densities and success in unmowed secondary roadsides than in mowed (13).

Fischer found North Dakota ditches contributing 2 percent of the area he searched, but 43 percent of the pheasant nests (11). In a similar study in North Dakota roadsides comprised 1.4 percent of the area searched and 57 percent of the pheasant nests (10). Bach and Stuart, also working in North Dakota, found 27 percent of upland game bird nests in roadsides that comprised only 2.6 percent of the area they searched (2).

In Nebraska, wheat fields and rights-of-way were where 92.2 percent of pheasant chicks were hatched (15). Chesness searched roadsides and drainage ditches in Minnesota and found that they accounted for 2 percent of the area searched but contained 25 percent of the pheasant nests (4). In a 1967 Nebraska study, 1.2 percent of the cover searched was roadside, but it yielded 28 percent of the duck nests and produced 47 percent of the ducklings (8). Another Nebraska study in 1967 involved 457 roadside pheasant nests (9).

NEST SEARCH PROCEDURE

A modified Varty drag (14) was used in 1968 and a cable drag (12) in 1969 to locate game bird nests. The Varty drag consisted of two 14-ft aluminum booms mounted on

a jeep. Flushing chains were placed at one-foot intervals on the booms. The cable drag consisted of a 185-ft, ⅝-in. steel cable towed between 2 jeeps, with overlapping loops of chain attached to the cable.

Because most upland game birds and puddle ducks dig nest bowls, neither the Varty nor the cable drag broke eggs. Hens were either flushed by the sound of the approaching drag or were scraped off their nests. In efficiency tests over known nests, both drags flushed about 75 percent of the hens.

Search speed was maintained at 3 to 5 mph. We used the cable drag in 1969 because its greater length permitted a complete search of the study area in 1 sweep, thus increasing efficiency and decreasing the number of crushed nests.

Birds were identified as they flushed from their nests. Vegetation parameters recorded at each nest site were plant species, composition, and height. Nest parameters included position on the right-of-way, location in the study area, number of eggs, adjacent land use, and distance from water. All data were punched or written on 91-hole Burroughs Unisort cards for easy retrieval.

The flotation method was used to determine dates of nest initiation and expected hatching (3, 16). Nest locations were mapped on highway department Interstate fencing plans, and marked by painting a number on the nearest post.

Nests were revisited on each successive search and 2 or 3 days after anticipated hatching date. Final fate of each nest was determined as successful, deserted, or destroyed by machine or mammalian or avian predator.

Sixteen nests that were deserted or destroyed by the search operation were included in location data but not in success ratios. Nest desertions not caused by searching were considered normal and were included in success ratios.

OPERATIONS AND RESULTS IN 1968

The study area was searched 3 times in the summer of 1968, and 130 game bird nests were located for a relative nest density of 5 acres/nest or 5.65 nests/mile. Nesting success was 58.8 percent for 114 nests of known fate. Predatory mammals accounted for 85 percent of nest destruction (Table 1). The peak weeks of waterfowl nest initiation and hatching for 1968 and 1969 were May 25 and June 22 (Fig. 1).

Waterfowl nests were uniformly located in mile blocks slated for mowing (59 nests) or nonmowing (61 nests). Nests on the right-of-way were predominantly positioned in the ditch bottom. Only 3 nests were located in interchange triangles in 1968.

Wildlife car-kills were recorded during May, June, and July by highway department personnel from the Medina sub-station. Skunks were the most common mammal (23)

TABLE 1

I-94 GAME BIRD NESTING ACTIVITY DURING 1968 AND 1969

Species	Number of Nests		Crushed or Deserted Nests[a]		Nesting Success[b]		Cause of Nest Failure							
							Mammal		Avian		Mower		Deserted[c]	
	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969
Mallard	25	25	4	-	6(28.5)	19(76.0)	12	6	1	-	1	-	1	-
Pintail	8	12	-	-	4(50.0)	10(83.3)	4	2	-	-	-	-	-	-
Gadwall	24	21	3	1	13(61.9)	8(40.0)	6	10	-	-	1	1	1	1
Blue-winged teal	50	59	7	2	29(67.4)	38(66.7)	12	14	1	2	-	-	1	3
Shoveler	13	11	2	1	6(54.5)	4(40.0)	5	6	-	-	-	-	-	-
Scaup	-	1	-	-	-	1	-	-	-	-	-	-	-	-
Subtotal, ducks	120	129	16	4	58(55.9)	80(64.0)	39	38	2	2	2	1	3	4
Mourning dove	1	1	-	-	-	1	1	-	-	-	-	-	-	-
Killdeer	1	1	-	-	1	1	-	-	-	-	-	-	-	-
Upland plover	8	2	-	-	8(100)	2(100)	-	-	-	-	-	-	-	-
American bittern	-	1	-	-	-	1	-	-	-	-	-	-	-	-
Total	130	134	16	4	67(58.8)	85(65.4)	40	38	2	2	2	1	3	4

[a]Search-caused crushed or deserted nests; these nests are not included in success ratios.
[b]Numbers in parentheses are relative success percentages.
[c]Normal nest desertions; these nests are included in success ratios.

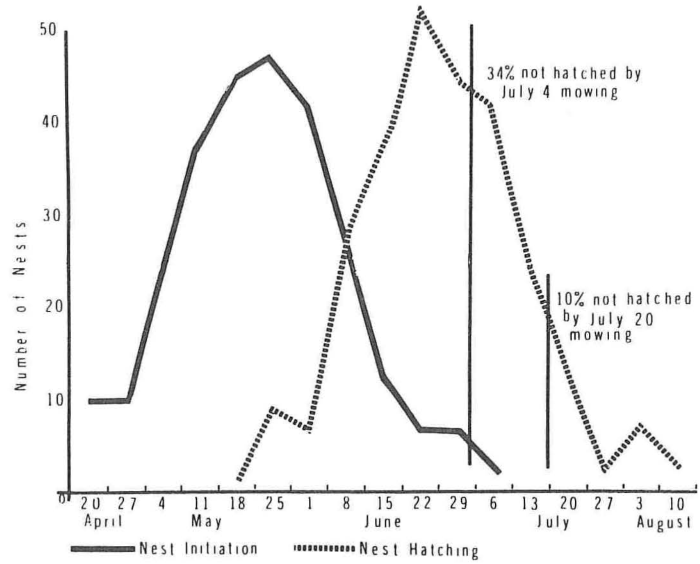

Figure 1. Initiation and hatching dates for 1968 and 1969 waterfowl nests on I-94; average clutch size of 10 eggs, average incubation period of 23 days, and laying rate of 1 egg per day used to estimate dates.

killed by cars in 1968. Five white-tailed deer were also killed in the study area in 1968 (Table 2).

Preparations for comparing the effects of mowing on 1969 game bird nest initiation and success began in June 1968 when the North Dakota State Highway Department and North Dakota State University entered into an agreement that called for mowing alternate mile strips of the study area. Mowing was permitted July 4 but began July 20, 1968, by the successful hay bidder and was completed in October 1968 by the highway department. Acreages of mowed and unmowed mileblocks were 312 and 318 respectively.

The pattern started at Crystal Springs and proceeded in alternate strips along the length of the study area. In no instance were specific mile blocks chosen for mowing or nonmowing treatment. The highway department was requested to mow any 2 of the 4 triangles at each interchange.

Publicity for the study was provided by Fargo radio and newspaper media and by displays on 4 rest area bulletin boards in and near the study area.

Four times during the 1968-69 winter snow cover measurements were taken at 21 mile-delineator posts to compare snow accumulation in mowed versus unmowed miles. Measurements were taken at the foot of the post (which is on the edge of the bituminous shoulder), at the toe of the inslope, and near the right-of-way fence.

Measurements on mowed-miles averaged 3.84 in. at the post, 11.57 in. at the inslope toe, and 12.95 in. near the fence. Unmowed-mile measurements averaged 4.18 in. at the post, 14.43 in. at the toe,

TABLE 2

WILDLIFE KILLED BY CARS ON I-94 IN 1968 AND 1969

Species	1968	1969
Striped skunk	23	0
Raccoon	4	1
White-tailed deer	5	3
Richardson's ground squirrel	1	0
Ring-necked pheasant	1	1
Ring-billed gull	2	0
Upland plover	2	0
Ducks	4	16
Badger	0	1
White-tailed jackrabbit	0	12
Gray partridge	0	1
Red fox	0	1
Burrowing owl	0	1
Total	42	37

TABLE 3

INCHES OF SNOW COVER ON MOWED AND UNMOWED SECTIONS OF I-94 IN WINTER OF 1968-69

Measurement Date	Mean Post Depth		Mean Inslope Depth		Mean Fence Depth	
	Mowed	Unmowed	Mowed	Unmowed	Mowed	Unmowed
12-14-68	1.57	1.86	3.14	5.10	4.81	7.05
12-27-68	2.38	2.62	7.24	8.62	8.05	11.81
1-14-69	3.10	3.05	9.14	11.86	12.67	15.57
2-28-69	8.33	9.19	26.76	32.24	26.29	26.33

and 15.19 in. at the fence (Table 3). In only 3 instances were mean snow depths significantly different between mowed and unmowed strips.

RESULTS OF 1968 MOWING CESSATION IN 1969

The study area was searched 3 times in 1969. One hundred thirty-four game bird nests were located for a relative nest density of 4.85 acres/nest or 5.83 nests/mile. Nesting success was 65.4 percent. Predatory mammals accounted for 84 percent of the nest destruction (Table 1).

Thirty-four (26.4 percent) of the waterfowl nests were located in mowed miles or triangles and 95 (73.6 percent) in unmowed miles or triangles (Table 4). The most chosen right-of-way nest position was the ditch bottom. Interchange triangles supported 18 nests.

Ducks and jackrabbits were most prevalent car-kill victims in 1969 (16 and 12 respectively). Skunks were surprisingly absent from the sample (Table 2).

Motorists' opinions regarding the appearance of mowed and unmowed conditions of the right-of-way were obtained in 182 interviews conducted at rest areas during May and June. Motorists were asked the following questions: Have you noticed the mowed-unmowed conditions of the right-of-way? Which condition do you prefer? Why do you prefer it? Do you prefer the mowed treatment in the face of high mowing costs?

The majority (81.9 percent) were unaware of the conditions of the right-of-way. When the mowed and unmowed conditions were pointed out, 72 percent preferred the mowed strips. Most of these (78.6 percent) retained their preference regardless of the high per-mile cost of such maintenance. Only seven of the 182 respondents preferred the unmowed condition (Table 5).

TABLE 4

I-94 GAME BIRD NEST LOCATIONS AND SUCCESS DURING 1969

Species	Nests Located in Mowed Blocks		Nests Located in Unmowed Blocks		Success in Mowed Blocks		Success in Unmowed Blocks	
	Number	Percent	Number[a]	Percent[a]	Number	Percent	Number	Percent
Mallard	1	4.0	24	96.0	1	—	18	75.0
Pintail	2	16.7	10	83.3	1	50.0	9	90.0
Gadwall	5	23.8	16	76.2	1	20.0	7	46.7
Blue-winged teal	23	39.0	36	61.0	15	65.2	23	67.6
Shoveler	3	27.3	8	72.7	1	33.3	3	42.9
Scaup	—	—	1	—	—	—	1	—
Subtotal, ducks	34	26.4	95	73.6	19	55.9	61	67.0
Upland plover	—	—	2	—	—	—	2	—
American bittern	—	—	1	—	—	—	1	—
Mourning dove	—	—	1	—	—	—	1	—
Killdeer	1	—	—	—	1	—	—	—
Total	35	26.1	99[b]	73.9	20	57.1	65	68.4

[a]Includes 4 search-caused or deserted nests that are not included in success columns.

[b]Significantly more birds chose unmowed mile blocks or triangles for nest sites; X^2 = 31.56 with 1 d.f., p less than 0.001.

TABLE 5

OPINIONS OF MOTORISTS REGARDING I-94 RIGHT-OF-WAY APPEARANCE

Question	Yes		No		Mowed		Unmowed	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Have you noticed the mowed-unmowed condition of the right-of-way?	33	18	149	82	-		-	
Which condition do you prefer?[a]					131	72	7	4
Do you still prefer the mowed condition in the face of high mowing costs?[b]	103	79	28	21				

[a]44 motorists (24 percent) had no preference.

[b]Includes only those who preferred the mowed condition in question 2.

To obtain an unbiased opinion, motorists were not informed about the nature of the study until after the interview, and interviews were taken at varying hours all days of the week to get a representative sample of the motoring public.

RIGHT-OF-WAY MOWING EFFECTS

While the 1968 and 1969 data show that waterfowl nesting density was high on I-94, the right-of-way is also used by many other species of wildlife, including upland plovers, American bitterns, killdeer, mourning doves, and a host of songbirds and mammals.

Relative waterfowl nest densities and nesting success on I-94 right-of-way compare favorably to waterfowl activities on other land use areas being studied in South Dakota and at Woodworth, North Dakota. High waterfowl nesting success was due in part to fewer predators along the highway. It is possible that red fox and other nest predators were deterred by highway traffic and did not frequent the right-of-way in normal numbers.

Cessation of mowing is beneficial for nesting success along rights-of-way. In 1968 nests were uniformly distributed between miles-to-be-mowed and miles-to-be-unmowed (59 and 61 respectively). In 1969, when the effects of mowing cessation were first seen, 95 nests were located in unmowed miles compared to only 34 in mowed miles.

Mallards showed the strongest response to cessation of mowing. In 1968, 14 mallard nests were located in miles-to-be-mowed and 11 were found in miles-to-be-unmowed. After the mowing treatment, only one mallard nested in mowed vegetation, while 24 were found in the heavier cover of unmowed miles (Table 4).

The appeal of unmowed right-of-way vegetation to nesting waterfowl is also evident in nest densities in interchange triangles for the 2 years. Only 3 nests in 1968 were located in triangles (which were all mowed in 1967), while 18 nests in 1969 were found in triangles, 13 of them (72.2 percent) in unmowed parcels.

Hatching success was higher for nests in unmowed mile blocks. Ducks nesting in mowed blocks were 55.9 percent successful, while 67.0 percent of the waterfowl nests in unmowed blocks hatched. For all species, mowed block nests were 57.1 percent successful and unmowed block nests were 68.4 percent successful. Mallards and pintails all showed remarkable hatching success in unmowed blocks (Table 4).

By cessation of mowing then, even for one year, we were able to attract ducks away from less productive locations on the right-of-way and increase their nesting success. It is possible that continued cessation of mowing will attract more ducks that are currently nesting in less profitable areas nearby.

But what ramifications does cessation of mowing have on right-of-way maintenance and appearance? Data given in Table 3 show that leaving mile blocks unmowed from the toe of the inslope to the fence does not increase snow buildup at the driving surface. Significantly more snow was found in unmowed blocks only once in the ditch bottom and only twice at the fence. No significant differences were observed between mowed and unmowed blocks at the driving surface.

It is not possible to determine the effect of cessation of right-of-way mowing on wildlife car-kills from our data, but it appears that numbers and species of animals killed by cars on I-94 reflect population changes to a great degree. Major shifts between 1968 and 1969 car-kills for skunks and jackrabbits are probably due more to changing population levels than to cessation of mowing.

The reduced number of predatory mammals in the 1969 car-kill sample could explain the overall increase in nesting success for that year, but it cannot explain the higher success in unmowed blocks.

The appearance of unmowed vegetation on the right-of-way is displeasing to many motorists only after it has been pointed out to them. A surprising number of motorists mentioned their enjoyment of seeing wildlife on rights-of-way, but these respondents did not equate wildlife with wildlife habitat. Many wanted to change their answers when the study was explained to them after the interview, fearing that their first answers would jeopardize wildlife on the right-of-way. It seems that the motoring public has been well impressed with the aesthetic value of wildlife but not with habitat requirements. The few motorists who preferred the unmowed condition explained their preference in terms of wildlife or ecology of the area. All of the respondents were congenial and cooperative and represented a wide range of home states.

LOWER MAINTENANCE COSTS—HIGHER WILDLIFE BENEFITS

Wildlife use of Interstate rights-of-way in the prairie pothole region of North Dakota, South Dakota, Minnesota, and Nebraska warrants management attention. Other portions of the Interstate System and other types of rights-of-way may be supporting other forms of wildlife and warrant investigation.

We have shown that location of duck nests can be manipulated by cessation of mowing schedules and even interchange triangles can be enhanced to produce waterfowl. In North Dakota at least, cessation of mowing on the Interstate right-of-way does not cause undue snow buildup on the driving surface, and motorists are largely unaware of the unmowed condition and probably can be educated in the need for wildlife habitat along Interstate rights-of-way to a point where they are tolerant of heavier roadside vegetation. Reduced mowing can be justified by lower maintenance costs and increased wildlife benefits and still be consistent with Interstate maintenance guidelines (1).

On the basis of the data presented in this paper, we recommend the following maintenance procedures for portions of the Interstate System in duck-producing regions:

1. Inslopes should be mowed only to the toe, and ditch bottoms, secondary slopes, backslopes, and fence lines should remain unmowed;
2. Interchange triangles should remain unmowed, except to the toe of the inslope; and
3. If mowing and haying must be carried out, they should be delayed until well past the peak of waterfowl nesting as determined by state and federal waterfowl biologists.

We urge state and federal highway personnel to seek continued cooperation with wildlife biologists in an intensified effort to manage the Interstate System and other types of roadside parcels for wildlife. Maintenance costs can be lowered and wildlife benefited at the same time. Encouragement and support to determine the long-term effects of cessation of mowing on right-of-way vegetation are essential in view of the fact that more and more states are tending toward reduced Interstate right-of-way mowing.

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Roadside Cover Equipment

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• THE WORK summarized here was initiated in 1958 at the Agricultural Engineering Department, University of Illinois, by the late George E. Pickard and covers several years of project activity. The main justifications for the project were the rapid increase of roadside acreages expected from the construction of the Interstate Highway System and the frequent failures of the equipment, techniques, and flora borrowed directly from agriculture to properly establish and maintain roadside cover. These failures were not too surprising because the conditions along roadside rights-of-way were radically different from those found in agricultural production. The cover was often grown on slopes seldom encountered in farm fields or even pasture land, and most of these slopes consisted of raw subsoil. The so-called superhighways had also produced deeper cuts and longer, sometimes steeper, slopes than those encountered in most of the past construction, and the problems of establishing cover had become more severe. Eighteen to 25 acres of grass per mile of Interstate highway plus an average of 40 acres per interchange helped to justify this project in which the effort was not only to find modest improvements but also to approach the problem as one where new cover species, new techniques, and new machines might be required.

The objective in the study was to develop and evaluate ideas and to formulate design principles and information that would lead to the production of equipment for more effective and economical roadside development and maintenance. A further and more immediate objective was to improve existing machines and develop more effective techniques for their use.

Studies of individual machinery problems were undertaken as the urgency of need appeared to dictate and as indicated by a national survey conducted by the project and previously reported (1). This survey of all state highway agencies and toll road authorities provided information on the types of equipment used for the establishment and maintenance of highway right-of-way and an assessment of their performance, convenience, and overall cost of operation. A project advisory committee was also quite helpful in selecting those areas needing investigation and in providing technical guidance.

The project involved several areas of activity that can only be summarized at this time. Detailed findings of the various phases of the project have been reported in several individual reports and publications, most of which are cited in the References.

TILLAGE, SEEDING, AND FERTILIZING

A survey indicated that about one-fifth of all new highway roadside seedings required reseeding at least once before cover was firmly established (1). In addition, the shoulders and ditches of older roadsides in agricultural areas where fall plowing is practiced require occasional reshaping to their original profile because of soil buildup in the roadside cover. Reshaping leaves large areas of bare shoulder and ditch that also must be reseeded. It was in the small area or "spot" reseeding and the reseeding of reshaped shoulders and ditches that an attempt was made to improve the equipment and practices used.

Work in Illinois and contacts with research personnel in other states indicated that small area reseeding was often a largely manual operation, costly in both labor and

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materials. If the operation was mechanized, a tractor was needed with a leveling blade, a disk harrow or other tillage tool, a fertilizer applicator, and a seeder. If only one tractor was available, rains occurring before the operations were completed often made it necessary to start over. If rain did not occur, the soil often was too dry by the time the seeding was made.

Exposed subsoil found on Illinois highway roadsides is nearly always extremely low in available nitrogen and phosphorus (2). Research has shown that the best response to fertilizer applied at seeding time is obtained when the fertilizer, especially phosphorus, is placed in the root zone and not in contact with the seed. After considering the conditions, project personnel concluded that a tractor-mounted implement was needed that would till the soil in 1 or 2 passes, apply fertilizer in the soil, drop the seed at a shallower depth than the fertilizer, and then firm the seedbed.

Three commercial machines were then obtained and used in seeding establishment trials during several seasons (3). The first machine obtained and evaluated was the Pasture Dream, produced by Taylor Machine Works (Fig. 1). This machine penetrated the soil with a set of rolling coulters, followed by fertilizer boots with hardened points that could penetrate to a 6-in. depth. Three hoppers permitted applying fertilizer, small grain or bulky seeds, and small-seeded grasses and legumes. Row spacings of 10 and 20 in. were possible.

The other 2 machines were the Deere 265 landscape seeder (Fig. 2) and the Deere MLF-6 fertilizer seeder (Fig. 3). The 265 landscape seeder had been modified at our request with a row of 12 flat spring teeth on a heavy mounting bar in front of the standard light leveling tines to permit tillage. The tillage teeth were later mounted in staggered form on 2 bars for better performance. Row spacings down to 6 in. were easily obtained. The MLF-6 was a heavier machine having larger hoppers, a stronger frame, and a higher center of gravity. Row spacings of less than 10 in. were difficult to obtain with the heavy coil spring teeth used for tillage (Fig. 3).

Many successful seedings were obtained with the units during trials on back slopes, shoulders, ditches, and interchange medians. However, several modifications were found necessary, and none of the machines was entirely satisfactory as available from the manufacturer. It appears that a machine should be designed and produced specifically for roadside use rather than modified from an existing machine.

We believe a satisfactory roadside tilling, seeding, and fertilizing machine would require the following design features. It should be lightweight, under 1,000 lb empty weight if possible, yet rugged enough to withstand severe use. Total hopper capacity should be limited to about 250 lb of fertilizer and 50 lb of seed mixture. A low center of gravity is desirable with an overall unit width of less than 7 ft. Tillage teeth should be 1- by 2-in. flat standard or 1-in. coil spring stock with provisions for a 3- to 4-in.

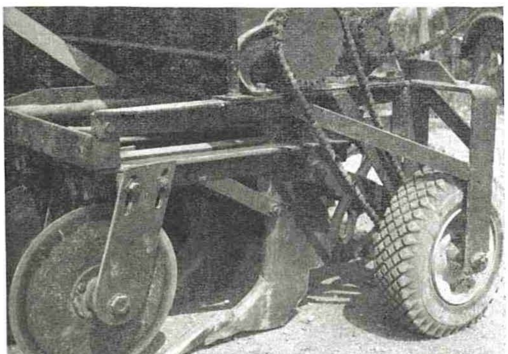

Figure 1. Relationship of hoppers and other components on Pasture Dream seeder.

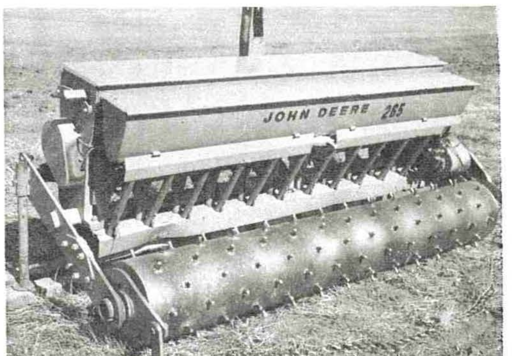

Figure 2. Spiked roller, drag chain, and feed tubes of Deere 265 landscape seeder.

flotation of each tooth. Two staggered rows of teeth should be used with 12-in. spacing in each row to give an overall 6-in. spacing. Fertilizer tubes should place the fertilizer behind the teeth and within 1 to 2 in. of tillage depth. Seed tubes should place the seed about 2 in. behind the fertilizer tube and in the soil about $\frac{1}{4}$ to $\frac{3}{4}$ in.

Provisions should be made for the operator to easily change the mode of machine operation from tillage alone to tillage and seeding or to tillage, fertilizing, and seeding so that varying numbers of passes can be made over the soil to ensure a good seeding under widely varying conditions. A 3-point hitch mounting should be provided, and the unit should be articulated in the center across the swath to permit the teeth to more nearly follow the soil profile. The pivot point should be about one-half the implement height and below the hoppers. Seeding rate capabilities should range from 10 to 150 lb/acre for any grass-legume mixture; fertilizing rates should range from 100 to 1,000 lb/acre. Soil should be firmed with a packer wheel behind each seeded row.

Figure 3. Deere MLF-6 fertilizer seeder as modified for first seeding trials.

Much more detailed information on the seeders, their use, and resulting recommendations is available in the report published on this phase of the project (3).

Another activity involved an analysis of particle trajectories and their application to a broadcast distributor that would spread a uniform application of seeds or granular fertilizers. The forces acting on a sphere moving through an undisturbed medium under the influence of gravity and the drag of the medium were characterized by a set of differential equations. Simulation with the aid of a general purpose, electronic, analog computer showed trajectories and variations in velocity and drag coefficient for several plastic spheres, seeds, and granular fertilizers. The drag coefficient varied considerably where the Reynolds number was low, and remained essentially constant at higher Reynolds numbers. Experimental verification of the analog solutions (Fig. 4) showed most actual trajectories within 10 percent of the theoretical solutions (4, 5).

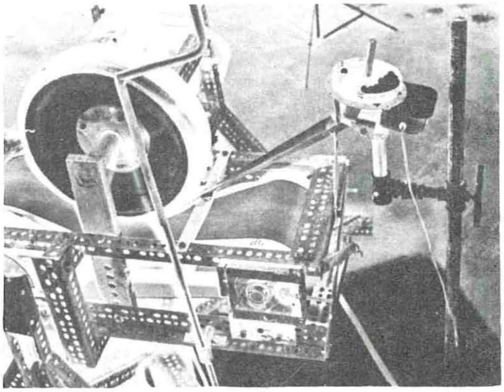

Figure 4. Apparatus used to throw individual particles to verify trajectory equations.

ROADSIDE MULCHING

Mulching with straw or other materials has become a standard practice when permanent seedings are established. A national survey indicated that most users felt the mulch blowers perform fairly well but some wanted a longer throw, a better feeding mechanism, and a mulch of individual strands rather than either bunches or short pieces. After field observations and user contacts, project engineers decided that a more even feeding of the baled material into the machine would provide less bunching of the applied mulch. The logical solution was to replace the manual feeding of bales into the mulcher with a mechanical feeding table. In addition to providing a more uniform mulch, this would eliminate one man from the op-

Figure 5. First version of mechanical feed table for delivering baled straw to mulcher.

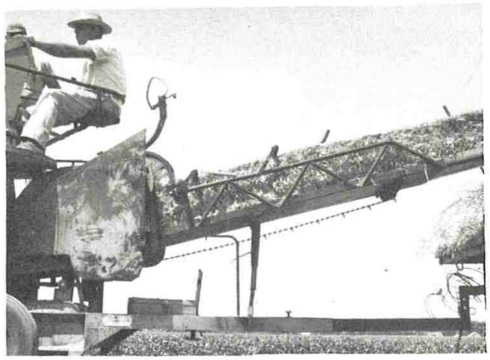

Figure 6. Second version of mechanized feed table with smaller bearings, longer feed chain teeth, and welded side rails.

eration, and the machine capacity should be increased because of more continuous feeding.

A commercial mulcher was obtained and adapted to mechanical feeding (6). Care was taken to make as few changes as possible in the rest of the machine to keep the adaptation simple and inexpensive (Fig. 5). The unit was used with some success during one season and then was modified considerably for the next season (Fig. 6). One of the most useful modifications was the addition of a solenoid control so the blower operator could stop and start the feeding to prevent overloads or to skip lanes and ditches.

This unit was so successful in meeting the design objective that Amalco, Inc., an Illinois landscape seeding contracting company, made up three more like it for its use. The feed table was accepted very rapidly by other landscaping contractors after the Finn Equipment Company introduced its version in 1965 (Fig. 7). At the present time, nearly all their large mulchers are sold with the mechanical feeding table.

To provide labor and time savings when unbaled mulches such as corncobs are applied to shrub beds and ground covers, an attachment for processing and conveying corncobs was developed (6). A large hopper and elevator (Fig. 8) were used to move cobs from dump trucks to crushing rolls (Fig. 9) that quartered the cobs before they passed into the mulch blower (Fig. 10). Additional versatility was later provided by simplifying the corncob processor so that other unbaled mulch materials such as sawdust, wood chips, and leaf litter could be handled (Fig. 11). In the later version the crushing rolls were removed and the flail chains in the mulcher were relied on to process the corncobs.

Figure 7. Production version of mechanical feed table.

Figure 8. Finn straw mulcher with modifications for applying corncob mulch.

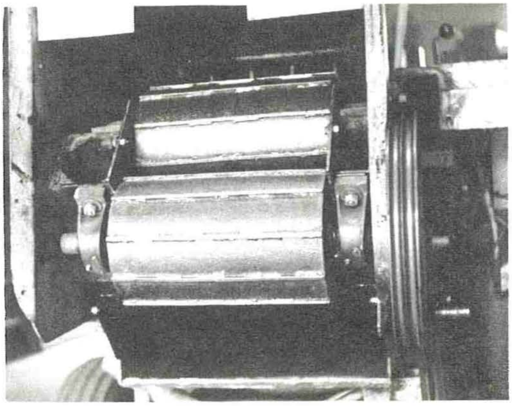

Figure 9. Crushing rolls mounted in throat of straw mulcher.

Figure 10. Shrub bed mulched with corncobs processed through modified mulcher.

MOWING OF ROADSIDE COVER

Sicklebar, horizontal rotary, and flail knife mowers are the most common machines used for cutting roadside grasses. The presence of rocks, rubbish, and debris is a hazard to all these mowers. The sicklebar mower will dull, chip, or break if it strikes obstacles. The horizontal rotary mower often throws objects, and these endanger operators, motor vehicles, and motorists. The flail knife mower has a high power requirement and excessive maintenance costs. Project activities in the area of mowing were primarily concentrated on the horizontal rotary mower (7, 8, 9) and the flail mower (10).

Research on horizontal rotary mowers began with observations of the movement of material through a specially prepared Ford rotary mower. The mower had been modified by placing transparent plastic plates in the top of the case through which the material movement could be studied by high-speed photographic techniques. Later, some of the plates were removed, and the effects of their removal on performance were evaluated. Preliminary studies indicated that a large amount of recutting occurred before the material was ejected from the mower and that this cutting action required a considerable amount of power. Observations also disclosed that windrowing was enhanced by material that was cut at the right side of the mower and moved to the left side between the knife tip and the case. Although observations were made with blades of different lift angles, the effect of these angles on the particle movement was not apparent.

Figure 11. Mulcher with revised hopper and elevator for unbaled mulches.

A mathematical description of particle movement on the blade was then undertaken, and equations of motion were derived for the forces and accelerations on a grass particle in a cylindrical coordinate system (7, 8). The analysis resulted in second-order, nonlinear, differential equations that were solved by Runge Kutta techniques with the aid of a digital computer. In an effort to verify the mathematical analysis, we developed a procedure for testing blades in the field by using high-speed photography to analyze particle trajectories from an open rotary mower

(Fig. 12). The results of this study indicated good correlation between the theoretical analysis and actual measurements of material movement in a horizontal rotary mower. It is apparent the blade lift angle is the most important single parameter influencing particle trajectory. Forward speed of the mower and initial particle position on the blade have little effect on particle path or exit velocity of the material. The average coefficient of friction of the material influences particle trajectory significantly, although to a lesser extent than the lift angle. Hence, for a mower with a given blade lift angle, material movement can be specified to some degree.

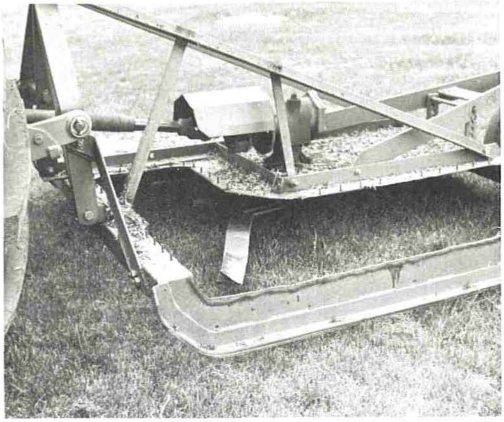

Figure 12. Horizontal rotary mower modified for verification of analytical solution of particle trajectories.

The next challenge was to apply the theoretical analysis to the design of a mower case utilizing the material movement to minimize power requirements, control the direction of flying objects, and eliminate most of the unwanted windrow. Two approaches were made to this problem (9): One involved the addition of an auger to the rear of the rotary mower discharge, and the other consisted of a shelf around the circumference of the blade with a paddle operating at one-quarter rotor speed to move the material and discharge it at the rear of the mower (Fig. 13). The first approach was abandoned after problems were encountered in transferring the material from the rotary blade to the auger assembly. A comparison was made between the shelf discharge mower and a conventional rotary mower in material that had an average height of about 10 in. There was a significant difference in the power requirements of the 2 mowers, with the shelf discharge mower requiring a lesser amount of power. This was primarily due to reduced recutting of the plant during movement in the mower case, a characteristic of the conventional rotary mower. The higher air velocity gusting out the rear of the standard mower was another indication of wasted power. A further comparison was made by using the shelf mower with 2 paddles versus 4 paddles to determine material distribution in the swath. In the case of both alfalfa and orchard grass, there was more even material distribution with 4 paddles.

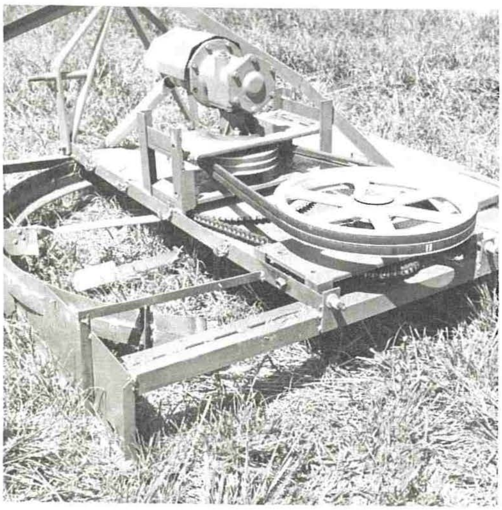

Figure 13. Shelf discharge mower with part of case removed; paddles move one-quarter the knife speed.

The wide range in flail mower knife sizes and shapes found on equipment in the field prompted project engineers to center the flail mower activity on improved knife design. The approach was to obtain the knife and material parameters needed from laboratory studies of a flail knife cutting a few typical materials and then supply the material characteristics to a computer program that would simulate the dynamic characteristics of a flail knife rotor assembly. In this way, it is possible to develop a flail knife design for a given set of conditions such as grass species used, rotor speed, cover height, and density.

From the analytical study of the dynamic characteristics of the flail knife, it was found that rotor speed and the radius

of the rotor are both very influential in the determination of the maximum deviation angle of the flail knife from a radial position during the cutting cycle (Figs. 14 and 15). The height of the crop cut by the flail knife was found to have much less influence on the maximum deviation angle than either the plant density or the energy required to cut one stem. The mass of the flail knife and the mass moment of inertia are proportional for the similar knife geometrics used for the study and have a large effect on the resultant deviation angles of the flail knife. There was close agreement between the theoretical equations derived and solved on the digital computer and the experimental results obtained on the flail knife laboratory test stand (10). Through the use of the digital computer program it was relatively easy to study the effect of the parameters involved on the entire system. The equipment designer should be able to use the equations developed to analyze flail knife design and greatly shorten test time required for an optimum design.

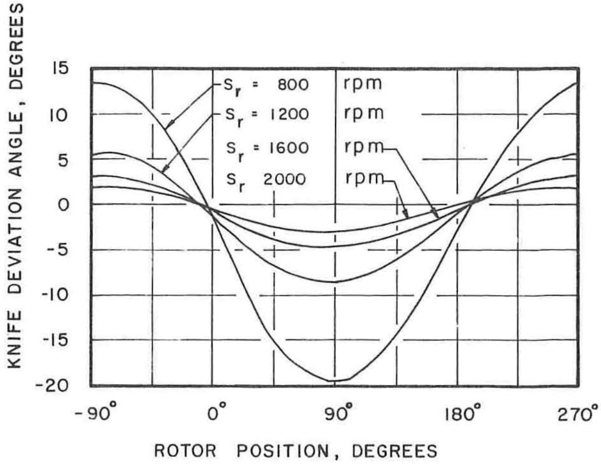

Figure 14. Effect on deviation angle of rotor speed, S_r (rotor position is expressed in deg).

SPRAYING ROADSIDE COVER

During the project activities on spraying, the special requirements of roadside spraying were studied, and modifications of equipment and developments of new components or concepts were then attempted (11). Concurrently, conferences and other contacts with commercial companies were used to encourage improvements in roadside sprayers.

Accurate spray application depends greatly on accurate nozzle output ratings and uniform nozzle spray patterns, so the nozzles were studied first. In addition to the boomless broadcast nozzles, regular flat fan tips and flooding fan tips were studied to compare operating characteristics. Because the boomless broadcast nozzles have the advantage of covering wide swaths, they can be widely spaced thus making it much easier to maneuver around or over obstacles. Nozzle plugging is seldom a problem, because large orifices are used. Besides producing a varied application rate across the pattern, they have the disadvantage of being difficult to overlap properly to get uniform coverage. Also, the swath width varies greatly with travel speed and with wind force and direction.

The regular flat fan and flooding flat fan nozzles have the disadvantage of requiring closer

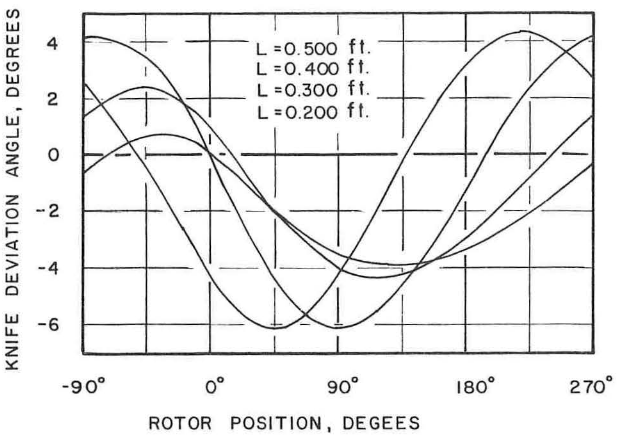

Figure 15. Effect on deviation angle of changes in rotor radius, L (rotor position is expressed in deg).

spacing along the boom. Clearing of signs, shrubs, and mailboxes without causing excess amounts of drift or skips in spray coverage is a major problem. Because the boomless broadcast nozzles seemed best overall, they were studied thoroughly with the hope of improving uniformity of pattern and developing a means of varying the swath width. The 2 most common boomless broadcast nozzles are the off-center nozzle and the radial flow nozzle. Both nozzles produce a pattern of fine droplets under the nozzle and very coarse droplets at the far end of the swath. An experimental radial flow nozzle was designed by project personnel. In tests of the experimental nozzle and 2 commercial nozzles, none had a really rapid drop in rate at the outer end for use at the right-of-way edge, although the experimental radial flow nozzle was best in this respect (Fig. 16).

After the nozzles previously mentioned had been examined and tested, a commercial sprayer was tested and a study was made of custom-operated and state-owned sprayers. Excessive pressure drop was a common fault with all sprayers as well as incorrect mounting of pressure gages, too low boom heights, slow-acting and inconveniently located shutoff valves, and booms that were difficult to pivot and raise.

The problem of nozzle pressure variation is more acute for spraying roadsides than for other types of spraying. The simplest and most economical way to correct this variation in pressure at each nozzle during spraying appeared to be to use an automatic flow regulator for each nozzle. Because commercially available automatic flow regulators were not found satisfactory, a study was made of the various bypass pressure regulators. On the basis of lowest permitted pressure rise, the single-spring, glass-ball, low-pressure regulator was best, and the 2-spring, diaphragm, low-high-pressure regulator was next best. Because it seemed desirable to obtain better control of pressure rise than any of the bypass regulators permitted, other means were investigated. The reduction type of flow regulator appeared to be a desirable alternative, for it not only presented the possibility of limited pressure rise on the nozzle side of the regulator but also eliminated the bypass line and its resulting friction losses. Tests of a $^{3}/_{4}$-in. IPT reducing type of regulator showed that it limited the pressure rise much more than the bypass type of valve. A 1-in. IPT reducing type of pressure regulator now used on a commercial highway sprayer limits the pressure rise of the boom during complete nozzle cutoff to 4 psi.

To get satisfactory swath width control, it was assumed that a 20-ft boom with a minimum swath of 20 ft and a maximum of 40 ft would be adequate in most cases. It seemed desirable to have the outer 20 ft of swath infinitely variable. Attempts to develop an infinitely adjustable nozzle were abandoned after several design efforts were

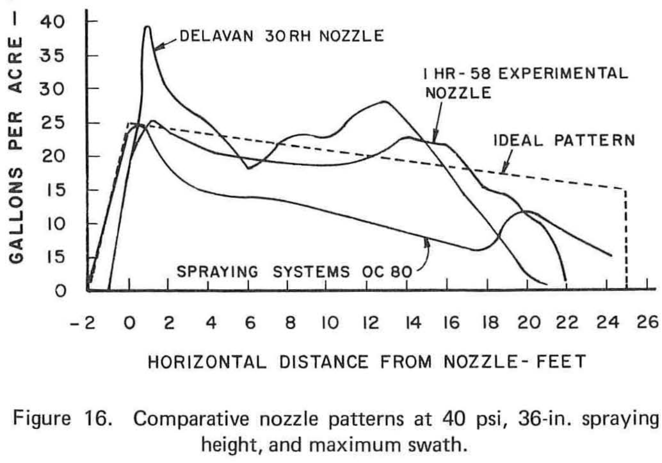

Figure 16. Comparative nozzle patterns at 40 psi, 36-in. spraying height, and maximum swath.

made toward covering and uncovering the orifice of the experimental radial flow nozzle. Nozzle heads were then developed that used a series of orifices to cover the swath in a series of discrete steps (Fig. 17). Figure 18 shows the nozzle head design that was developed and accepted commercially. It uses commercial nozzle tips to cover each segment of the swath and a rotary cutoff valve to control the number of segments and hence the spray width. It has certain advantages in that the control linkage can be a simple pinion and rack operated by push-pull cable; therefore, proper overlaps are easy to obtain by selection of nozzles. Wear on the rotary valve is easily taken up by the spring loading, and wear in the nozzle tips is no problem because they can be replaced without disassembling the nozzle body. On November 19, 1963, U.S. Patent No. 3111268 was issued on the remotely controlled spray head. As a result of this work, Deere and company of Moline, Illinois, became interested in the nozzle head and was licensed to use it on a roadside sprayer they were developing (13).

Figure 17. Rotary valve, adjustable swath, nozzle assembly equipped with rack and pinion, with rack operated by push-pull cable.

VEHICLE STABILITY

The purpose of this investigation was to formulate and analyze a mathematical model that would be suitable for studying and predicting the steady-state behavior of a tractor operating along roadside slopes (13, 14). It was hoped that a method of predicting vehicle behavior might be found so that safety of operations, as well as functional design, could be improved. Various parameter values were used in a computer analysis to study the effects of tractor geometry, including drive and steer design possibilities. Input data for the model were obtained from studies of 3 different tractor and mower units, one of which was equipped with special tires (Figs. 19, 20, and 21). The model was then used to simulate behavior of several hypothetical vehicle designs under typical slope conditions.

With 4-wheel steering, it is possible to eliminate yaw of the vehicle with respect to the desired direction of travel. The yawing of the vehicle, however, does affect the lateral stability and therefore the 4-wheel steered vehicle is somewhat less stable in that regard on steep slopes than is the conventional front-steered vehicle. The

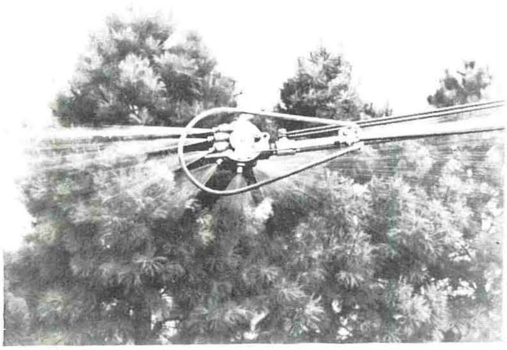

Figure 18. Deere version of adjustable swath, rotary valve, nozzle assembly (all nozzles operating).

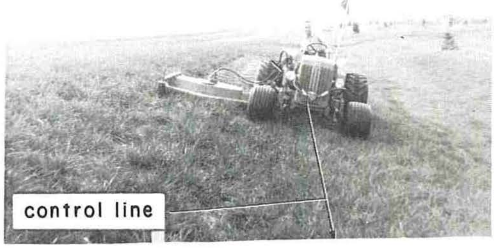

Figure 19. Tractor A with side-mounted rotary mower.

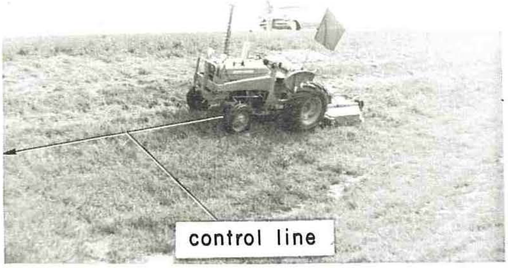

Figure 20. Tractor B_1 with rear-mounted rotary mower.

Figure 21. Tractor B_2 with side-mounted sickle-bar mower.

most favorable design for preventing sliding is a 4-wheel drive, and the least favorable of those considered is the front-wheel drive vehicle. On the slopes considered, sliding was the mode of failure always experienced under the steady-state operating conditions.

The dynamic behavior of vehicles operating on slopes was considered in a second phase of the study (15, 16). The tractor and implement were represented as a series of rigid bodies supported on tires having linear spring rates and constant damping coefficients (Fig. 22). The tire characteristics were evaluated independently in the vertical, lateral, and longitudinal directions. The vehicle was modeled with 9 deg of freedom resulting in a set of 9 simultaneous, second order, differential equations. Numerical integration was effected via the Runge Kutta method with the aid of a digital computer. Output, in the form of a displacement of any point on the vehicle and in either the vertical, lateral, or longitudinal direction plotted against time, could be obtained.

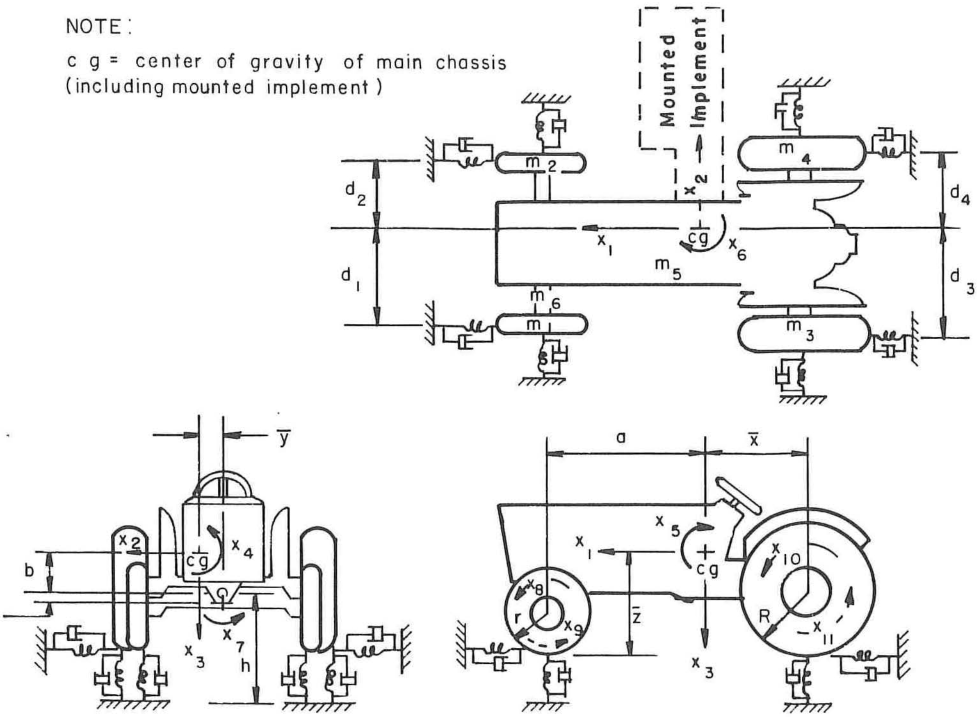

Figure 22. Dynamic tractor system.

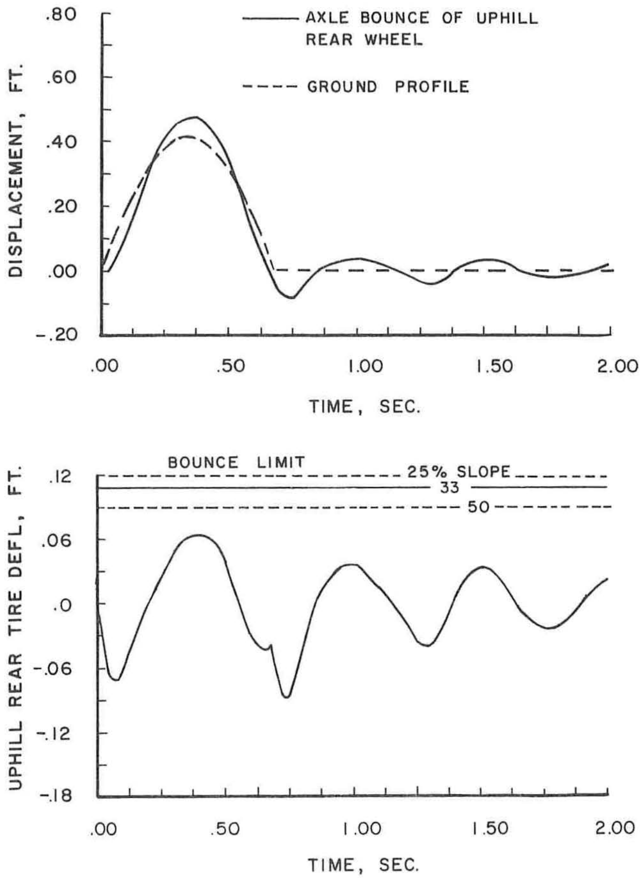

Figure 23. Transient response of tractor for standard conditions.

For all cases studied, the input was in the form of a single bump traversed by the uphill rear wheel. A standard sinusoidal bump having a height of 5 in. and a length of 3 ft was used with forward travel speeds of 3, 4.5, and 6 mph. The tractor that was simulated was dynamically stable on all slopes up to 50 percent when operating at 3 mph over the standard bump (Fig. 23). The tractor wheel lost contact with the ground at 4.5 mph on 25 percent slopes and at 6 mph on flat slopes and was considered to be in an unsafe condition. The ride was improved when spring rates were reduced 50 percent and damping was doubled. This partially illustrates the potential of a separate suspension system between the chassis and the wheels. The addition of a side-mounted implement located on the uphill side improved the stability, even though the actual bounce motion was greater for the conditions studied. There was a considerable difference in the transient response of the tractor modeled with 9 deg of freedom as compared to the more conventional, simplified 3 deg of freedom model. This points to the need for careful consideration in selecting the degrees of freedom for a mathematical model used in simulation.

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THE NATIONAL ACADEMY OF SCIENCES is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as an official—yet independent—adviser to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

The NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

The NATIONAL RESEARCH COUNCIL was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U.S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial, and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

The DIVISION OF ENGINEERING is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

The HIGHWAY RESEARCH BOARD, an agency of the Division of Engineering, was established November 11, 1920, as a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of transportation. The purpose of the Board is to advance knowledge concerning the nature and performance of transportation systems, through the stimulation of research and dissemination of information derived therefrom.

HIGHWAY RESEARCH BOARD
NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL
2101 Constitution Avenue Washington, D. C. 20418

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